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The Importance of Host-Feeding by Adult Parasites in the Reduction of Host Populations[1]

PAUL DE BACH, *University of California Citrus Experiment Station, Riverside*

Students of the parasitic Hymenoptera have known since Marchal's first report, in 1905, that various species of adult parasites ingest the body fluids of their hosts. Howard (1910), a few years later, drew further attention to this phenomenon and predicted that it would be found to be widespread. More recently, Clausen (1940) has discussed host-feeding by species of the Pteromalidae rather completely, and mentions that it occurs in species of other families of the Chalcidoidea, as well as in certain of the Braconidae and Ichneumonidae.

Undoubtedly the habit of host-feeding by adult parasites, or host-predatism as it may be termed, is much more extensive, from the standpoint of the number of families and species involved, than is recorded at present. Although of great interest as a biological phenomenon, host-feeding is probably of greater interest to economic entomologists in its ecological rôle.

That host-feeding by adult parasites may be of epidemiological importance in the reduction of host populations has not been generally recognized up to the present time. A few authors, however, have commented on the relatively great mortality caused by the host-feeding of certain parasitic species. The only quantitative results are those reported by Johnston (1915) concerning the asparagus beetle egg parasite, *Tetrastichus asparagi* Cwfd. His data show that, of 2097 host eggs in the field, 71 per cent were killed by host-feeding alone. In the laboratory, 19 females having an average life of about 7.5 days, fed upon 518 hosts but parasitized only 279. This 65 per cent host-feeding mortality confirms very closely that observed in the field. In Johnston's opinion, ". . . [*Tetrastichus*] appears to be of greater value as an egg destroyer than as a parasite developing within the host."

In view of the undoubted widespread occurrence of host-feeding among parasitic species and, as shown in the present paper, the important rôle which host-feeding by adult parasites plays in the reduction of the host populations, it will in the future be highly desirable for entomologists engaged in biological control to ascertain whether a parasitic species exhibits host-feeding. If such be the case, adequate steps should be taken for the measurement of this mortality factor, which, as with *Tetrastichus asparagi* and the asparagus beetle *Crioceris asparagi* (L.) and as with *Metaphycus helvolus* (Comp.) and the black scale (*Saissetia oleae* [Bern.]), may be relatively more important than parasitization.

The black-scale parasite *Metaphycus helvolus* (Comp.) is now credited with having brought about another example of successful biological control (Smith 1942). During the early phases of its establishment, however, the question often raised was whether the observed black-scale mortality was due to parasites or to other causes. This was probably owing, in good part, to the fact that some observers saw black-scale infestations having a high degree of parasitization, whereas others saw infestations having a high degree of mortality but little or no parasitization, the dead scales being flattened and dry. Surprisingly enough, as has now been demonstrated, both types of mortality are caused by *M. helvolus*.

Mortality caused by the feeding of adult females of *Metaphycus helvolus* upon the black scale accounts for the flattened

[1] Paper No. 494, University of California Citrus Experiment Station, Riverside, California.

and dried condition of the host. Flanders first discovered this phenomenon in 1939 and has discussed its biological aspects rather fully (Flanders 1941, 1942a, b). Briefly, the adult females of *M. helvolus* must periodically feed upon their hosts in order to insure development of their full complement of eggs. Host-feeding by the adult parasite is accomplished by sucking a portion of the contents of a black scale through a wound made by the ovipositor. The result is the death of the scale.

Extensive field mortality of black scale, caused by the host-feeding of adults of *Metaphycus helvolus*, was noticed in 1941–42 in the course of intensive investigations by the writer into the effectiveness of *M. helvolus* as a control agent. That is, since control tests showed that *M. helvolus* was the responsible factor in the black-scale mortality, and since the parasitization was much too small to account for the total mortality, the additional mortality was ascribed to host-feeding. By the use of organdie sleeves, it was possible, in these tests, to exclude the parasites from selected scale-infested citrus branches in closed sleeves, while permitting the parasites to have access to other branches where the outer ends of the sleeves were left open. In view of the results of these experiments, which, over a period of nine months, showed a marked discrepancy between total mortality caused by *M. helvolus* and parasitization, further tests were devised, both in the field and in the laboratory. These tests were planned in such a way as to allow analysis of the relative importance of parasitization and host-feeding by *M. helvolus*, and to show the influence of several factors, such as host size, host density, and parasite density, upon the two types of mortality.

FIELD STUDIES.—As reported by Smith (1942), field tests bearing upon the relation of host-feeding mortality to mortality caused by parasitization were initiated in December, 1941, and continued until May, 1942. On December 8, 1941, two closed organdie sleeves on navel-orange branches containing healthy infestations of small black scale, 1 to 3 mm. in length, were selected for the present studies. Twenty leaves and 10 5-inch twigs in each sleeve were tagged and counted for black scale. Sleeve No. 1 was left unchanged, but 20 females of *Metaphycus helvolus* were introduced into sleeve No. 2. The scales on the tagged leaves and twigs were counted each month and represent an adequate sample of the total scale population in each sleeve. Natural mortality in the sleeve without parasites has been taken into account, so that host-feeding mortality can be determined readily as the difference between total mortality caused by *M. helvolus* and mortality caused by parasitization. The results of the counts made in the sleeve containing introduced parasites are shown in table 1.

Table 1.—Black-scale mortality caused by parasitization and host-feeding by *Metaphycus helvolus* (Comp.); Riverside, California; December, 1941, to May, 1942.[1]

Month	Initial Number of Live Scales	Total Mortality	Scales Killed by Parasites		
			Total[2]	By Parasitization	By Host-Feeding of Adults
			Number	Per Cent	Per Cent
First	418	136	46	0.0	11.0
Second	282	220	188	7.8	58.9
Third	62	49	49	50.0	29.0
Fourth	13	5	5	38.5[3]	0.0
Fifth	8	8	8	100.0	0.0
Total or Average	418	418	296	15.8	55.0

[1] Twenty female parasites were introduced into one closed sleeve on citrus, December, 1941.
[2] Corrected for natural mortality obtained in sleeve without parasites.
[3] Approximate, because of experimental error inherent at low population densities.

A striking feature of these results is the total extermination of black scale in the sleeve containing introduced parasites. Although this may be comparable to what occurs in small areas in the open, parasites, of course, rarely if ever exterminate their hosts over large areas.

The number of scales killed by the host-feeding operation, which occurs largely when the scales are rather small for parasitization, is much greater than the number killed by parasitization. As the scales increase in size, the percentage of parasitization increases rapidly, although, of the original population, the total number parasitized remains low. During the fourth and fifth months of the tests, the scale population was so very low that small sampling errors may be greatly magnified (Table 1). For this reason it is not safe to assume that no host-feeding occurred during this period, because it undoubtedly did, but to a much more limited extent than before. The safest conclusions to draw from these data are those based on the total mortality of the

original population. Of the 70.8 per cent mortality caused by *Metaphycus helvolus*, only 15.8 per cent was caused by parasitization, whereas 55 per cent was caused by host-feeding. Expressed otherwise, the ratio of scales parasitized to scales killed by feeding of adult parasites was approximately 1:3.5.

These results confirm very closely the scale mortality observed in 1941 in field sleeve studies in which the mortality was known to be caused by *Metaphycus helvolus* but could not be ascribed to parasitization. This mortality, now definitely known to be caused by host-feeding, follows very closely the trends apparent in table 1. For instance, data reported in table 2 show that, in open sleeves on the

Table 2.—Black-scale mortality caused by parasitization and host-feeding by *Metaphycus helvolus* (Comp.); Santa Paula, California; September, 1941, to April, 1942.[1]

Month	Initial Number of Live Scales	Total Mortality	Scales Killed by Parasites: Total[2] Number	By Parasitization[3] Per Cent	By Host-Feeding of Adults Per Cent
First	2047	477	477	4	19
Second	1570	956	956	5	56
Third	614	297	264	8	35
Fourth	317	113	92	15	14
Fifth	204	91	80	26	14
Sixth	113	36	34	30	0
Seventh	77	37	37	42	7
Total or Average	2,047	2,007	1,940	19	78

[1] Parasites entered the five open sleeves of these tests from the field. Sleeves were opened in July; first trace of parasitization (1 per cent) occurred in August.
[2] Corrected for natural mortality obtained in sleeves without parasites.
[3] Some scales with emergence holes remained on leaves and twigs and were included in succeeding counts; therefore, these figures are not exact counts.

Limoneira Ranch, Santa Paula, Ventura County, California, which *M. helvolus* entered from the field, the parasite caused 97 per cent mortality over a period of 7 months. In table 2, as in table 1, it is shown that the number of scale killed by host-feeding (1560) was much greater than the number killed by parasitization (380); and that the host-feeding occurred largely when the scale was small and the parasite population was just getting started; also, that as the scale grew in size, the percentage of parasitization increased rapidly, although, considering the original population, the total number parasitized remained low. The percentage of scale killed by host-feeding also followed a trend similar to that shown in table 1, by increasing somewhat during the early growth of the parasite population and then declining. Of the total mortality of the original scale population, 97 per cent was caused by the activities of *M. helvolus;* of this amount only 19 per cent was caused by parasitization, whereas 78 per cent was caused by host-feeding. In this case the ratio of scales parasitized to scales killed by feeding of adult parasites was approximately 1:4.

Several interesting questions are suggested by the preceding data. Is increase in parasitization, with time, correlated with an increase in the size of the scale or with a decrease in the scale population, or with both? Conversely, is decrease in host-feeding mortality, with time, correlated with an increase in scale size or with a decrease in scale population, or with both? Further, does an increase in the number of parasites have any effect upon the relation of parasitization to host-feeding mortality?

Scale size (or age), scale population density, and parasite population density are the only known variable factors involved; the effect of any one can therefore be analyzed by holding the other two constant in appropriate experimental tests. This was carried out in laboratory experiments.

LABORATORY STUDIES.—A study of the effect of relative numbers of adult females of *Metaphycus helvolus* and black scale on black-scale mortality caused by host-feeding and by parasitization was undertaken.

Effect of Parasite Numbers.—Single, potted potato sprouts infested with suitable-sized scale were used. Each sprout was covered with a glass lamp chimney having an organdie cover over the top. Since the number of scale per sprout varied somewhat, sufficient replications were planned to make possible the elimination of any effect of host density. The effect of parasite density may be determined by averaging the results of the replications; the effect of the host density, on the other hand, is brought out by analysis of the data for individual sprouts. Twenty black-scale-infested potato sprouts were placed in four series of five sprout replicates each. One series was set aside as a control, having no parasites; one series received 1 female *Metaphycus* per sprout; another series received 5 fe-

Table 3.—Effect of the number of adult females of *Metaphycus helvolus* (Comp.) on black-scale mortality caused by host-feeding and by parasitization (one parasite generation).

Numbers				Scales Killed by Parasites		
Sprout Replicates	Parasites Per Sprout	Initial, Live Scales	Average, Scales Per Sprout	Total[1]	By Parasitization	By Host Feeding of Adults
				Number	Per Cent	Per Cent
5	1	1451	290	636	17	27
4[2]	5	1038	260	815	18	60
4[2]	10	1108	277	940	15	70

[1] Corrected for natural mortality. [2] One sprout died.

male parasites per sprout; and another, 10 female parasites per sprout.

Data obtained from these tests are presented in table 3. Results are presented graphically in figure 1, which shows that, within the limits of these tests, per cent parasitization[1] is not significantly affected by parasite numbers. The percentage of scale killed by host-feeding is markedly affected, however, and follows a general upward trend as the parasite density increases. From 27 per cent, at a density of 1 parasite per sprout, host-feeding mortality of scale rises to 60 per cent at 5 parasites per sprout, and then continues to 70 per cent at 10 parasites per sprout. No direct comparison can be made between these data and data from the field studies, since we are concerned with but one generation[2] of parasites in the laboratory as opposed to several generations in the field. The fact is apparent, nevertheless, that again host-feeding mortality is much greater than parasitization. An increased number of hosts, that had already

[1] Throughout this paper, "per cent parasitization" refers to scales from which adult parasite progeny were produced; scales receiving parasite eggs which for any reason failed to mature are ignored.

[2] By one parasite generation is meant the time required for the progeny of a female parasite to reach the adult stage, that is, approximately two weeks in the laboratory.

Table 4.—Effect of black-scale density on black-scale mortality caused by host-feeding and by parasitization by *Metaphycus helvolus* (Comp.). (One parasite generation.)

Series & Potato Sprout No.	Numbers			Total Mortality	Scales Killed by Parasites		
	Parasites Per Sprout	Black Scales Per Sprout			Total	By Parasitization	By Host-Feeding of Adults[1]
		Initial	Final[3]		Number	Per Cent	Per Cent
1–1	1	190	90	100	89	14.7	32.1
2	1	210	118	92	79	17.6	20.0
3	1	220	48	172	159	16.8	55.5
4	1	397	253	144	120	18.1	12.1
5	1	434	219	215	189	16.1	27.4
2–1	5	135	3	132	124	11.1	80.7
2	5	237	12	225	211	13.1	75.9
3	5	296	38	258	240	17.6	63.5
4	5	370	108	262	240	24.3	40.5
3–1	10	166	1	165	155	8.4	84.9
2	10	217	5	212	199	11.5	80.2
3	10	219	1	218	205	9.6	84.0
4	10	506	94	412	382	20.6	54.9
4–1[2]	0	157	135	22	...	....	....
2	0	302	295	7	...	....	....

[1] Corrected for natura mortality. [2] Controls. [3] After 13 days.

received a parasite egg, are fed upon by the parasites. Host-feeding therefore tends to maintain a uniform production of adult parasites.

Effect of Host Density.—Table 4 includes the data obtained from the three parasite-density categories (1, 5, and 10 females per sprout) as analyzed for the effect of black-scale density upon parasitization and host-feeding mortality. These data are presented graphically in figure 2.

Figure 2, A, shows the relation between parasitization and host-feeding mortality at different black-scale population densities, with 1 female parasite per sprout. The variation inherent in normal egg production of individual female parasites accounts for the widely separated points apparent on the curves. General trends are distinguishable, however: Per cent parasitization increases with host population density until the maximum parasite reproduction is reached, and then declines. Per cent host-feeding mortality probably follows the same type of curve, although the relation is somewhat obscure. Per cent host-feeding mortality is greater than per cent parasitization, especially at the lower host densities, but tends to decline and approach per cent parasitization at the high densities. This decline is probably explained by the fact that host-feeding mortality reaches its optimum at a lower

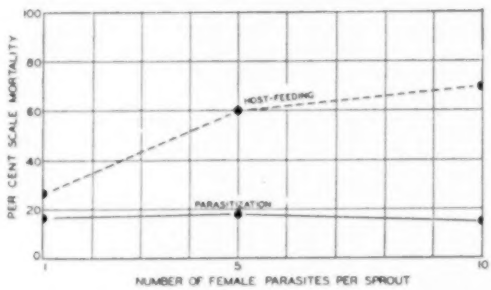

FIG. 1.—Relation between the number of females of *Metaphycus helvolus* per black-scale-infested potato sprout and the per cent scale mortality caused by host-feeding and by parasitization.

host density than does parasitization; further increases in host density therefore do not affect host-feeding but result in a decline in host mortality when expressed in per cent.

Figure 2, B, illustrates the relation between per cent parasitization and per cent host-feeding mortality at different black scale population densities, with five female *Metaphycus helvolus* per sprout. The general trends are clear-cut: Per cent parasitization gradually increases at the higher host densities; per cent host-feeding mortality decreases rather rapidly with increases in host density. The most striking fact to be gleaned from these data is that, under unfavorable conditions such as a high ratio of parasites to hosts, host-feeding by the parasite is relatively more favored than parasitization. At low host population densities, initial host-feeding activities of the parasite, which tend to precede oviposition (Flanders 1941, 1942b), so deplete the scale population that there are very few scale left for oviposition purposes. At the higher host population densities, however, even though more host-feeding occurs, a greater

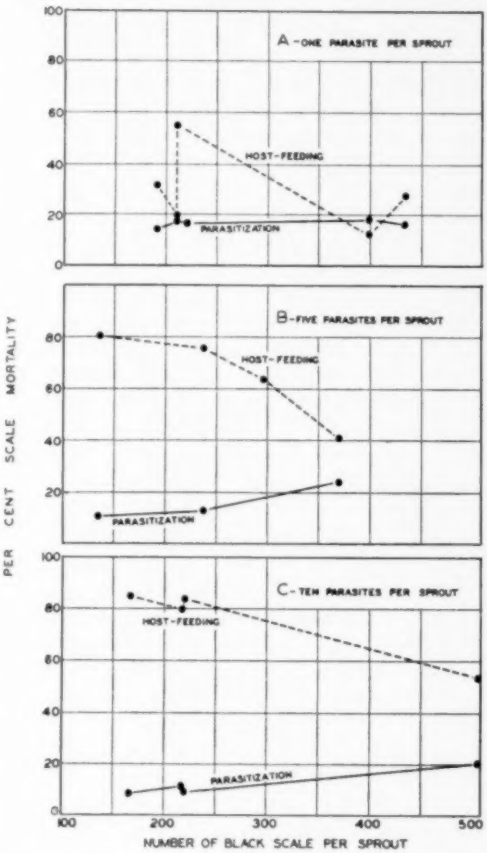

FIG. 2.—Relation between black-scale density per infested potato sprout and the per cent scale mortality caused by host-feeding and parasitization by 1, 5, or 10 females of *Metaphycus helvolus* per sprout.

number of scales are still available for parasitization.

A seeming paradox presents itself when the data obtained from tests with one and with five female parasites are examined. From table 4 it is evident that, under conditions of optimum host density (397 and 434 scales), one female parasite will parasitize about 70 scales and require approximately 85 scales for feeding; and that, under less favorable conditions of host density (190 and 210 scales), the minimum per female is about 30 scales parasitized to 50 scales fed upon. Applying even these minimum mortality figures to the tests where five female parasites were used, we should expect, offhand, that all the scales would be killed, even on the sprout having the greatest number of hosts (370), since five females should be able to kill at least 400 scales. The greatest total number of scales killed by five females was actually only 240. The question that naturally arises is: Why do these other scales escape when the parasites, either by host-feeding or by parasitization, are potentially able to kill them all? Three likely possibilities suggest themselves: superparasitization, feeding on parasitized hosts, and host-conditioning.

Superparasitization naturally tends to be greater at higher parasite densities, since the chance that a female parasite may oviposit in a scale already parasitized increases as the number of parasites increase. On the other hand, if *Metaphycus helvolus* can distinguish between parasitized and unparasitized hosts, which is likely, superparasitization may, in part, be avoided. The ability of the parasite to avoid superparasitization is, of course, influenced by the number of host scale present, as well as by the number of adult parasites present.

A scale already bearing a parasite egg or larva may be fed upon and killed by an adult parasite. As in the case of superparasitization, such feeding will tend to be greater at the higher parasite densities. This phenomenon, therefore, may result in a reduction in apparent parasitization.

Whether, as with superparasitization, female parasites can detect that a scale is already parasitized and can thus avoid feeding on a parasitized host, is an open question. Certainly, the end in view is not the same. It may be, however, that a parasitized scale tends to repel an adult female parasite, whether she be interested in oviposition or in host-feeding. If this is the case, feeding on parasitized hosts may, to a certain extent, be avoided. Higher host densities will also tend to reduce the amount of such feeding which occurs. Our lack of knowledge of the problem of feeding on parasitized hosts makes general conclusions impossible; but such feeding undoubtedly is of some quantitative importance, the magnitude of which remains to be worked out.

The ability of the parasite to avoid superparasitization and feeding on parasitized hosts may partially account for the increase in parasitization shown in table 4 and in figure 2, B. If, however, both superparasitization and feeding on parasitized hosts decrease at the higher host densities, why are so many scale left alive? Host conditioning, the phenomenon described by Salt (1937), which causes female parasites to avoid hosts contaminated by the examination or contact of other female parasites, may be the answer.

Host conditioning is a relative process: a female tends to avoid a contaminated host as long as the pressure of host-feeding or oviposition is not too great. Under conditions of stress, however, this mechanism may break down. For this reason, 5 females kill nearly all (91.8 per cent) of their hosts at a low density of 135 scales per sprout. At a density of 370 scales per sprout, 5 females kill a greater total number of scales (262), but since they are therefore under less stress to attack conditioned scale, the result is that only 64.8 per cent of the scales are killed by the 5 parasites, which are potentially able to kill all 370 scales.

The explanation of the tendency for per cent host-feeding mortality to decline, while per cent parasitization increases, is probably that which has been suggested above. The biological reason for the obtaining of such results is that *host-feeding is necessary for continued oviposition; it therefore takes preference over oviposition and so at the lower host densities accounts for a relatively greater portion of the mortality.* At the higher host densities, there are a sufficient number of hosts to take care of host-feeding by parasites and to allow for a relative increase in parasitization.

Figure 2, C, illustrates the relation between per cent parasitization and per cent

host-feeding mortality at different black-scale population densities, with 10 adult females of *Metaphycus helvolus* per sprout. The general trends agree closely with those shown in figure 2, B, in that there is a gradual increase in per cent parasitization and a decrease in per cent host-feeding mortality at the higher host densities. The main difference is that, with 10 female parasites, the increase in per cent parasitization and the decrease in per cent host-feeding mortality are much more gradual at the higher host densities. However, the highest host density (506) with 10 parasites is probably comparable to a host density of 250 with 5 parasites. If the two curves are compared in this light, they are very similar.

Only at the highest densities shown in figure 2, B and C, where 5 and 10 female parasites were used, respectively, were there sufficient scales for many to be left alive, although, of course, in both cases the parasites were potentially able to destroy all the hosts. That they failed to do this is again referable to the phenomena of superparasitization, feeding on parasitized hosts, and host conditioning, which operate along with ovipositional restraint on the part of the parasites.

Throughout the preceding discussion we have been considering the effects of host density upon parasitization and host-feeding mortality from the standpoint of the host populations. The individual work done per female parasite at different host densities is obscured by such a presentation. It is a simple matter, however, to obtain data on this point from the material in table 4. These data, which show the relative importance of parasitization and feeding mortality per individual female of the three parasite density groups (1, 5, and 10 parasites per sprout) at different host densities, are illustrated in figure 3, A and B.

Figure 3, A, shows clearly the effects of competition between parasite females upon parasitization per female: the greater the number of females, the less the parasitization per female. This seems to hold true even for the higher host densities.

With 1 female parasite per sprout (Fig. 3, A), parasitization per female increases, with host density, from 28 scales parasitized at a host density of 190, to 70 scales parasitized at a host density of 434. Above a host density of 400, the maximum number of eggs (about 70)[1] per female generation was probably reached, and the curve levels off.

With 5 female parasites per sprout (Fig. 3, A), parasitization per female increases with host density much more slowly and is much lower than that recorded in the curve for 1 female per sprout. A much greater host density would have to occur per sprout to enable the curve to approach the point at which it would level off because of a lack of eggs on the part of the female parasite. Such a density was impracticable in these tests, since 500 scales is about the maximum that a sprout can support.

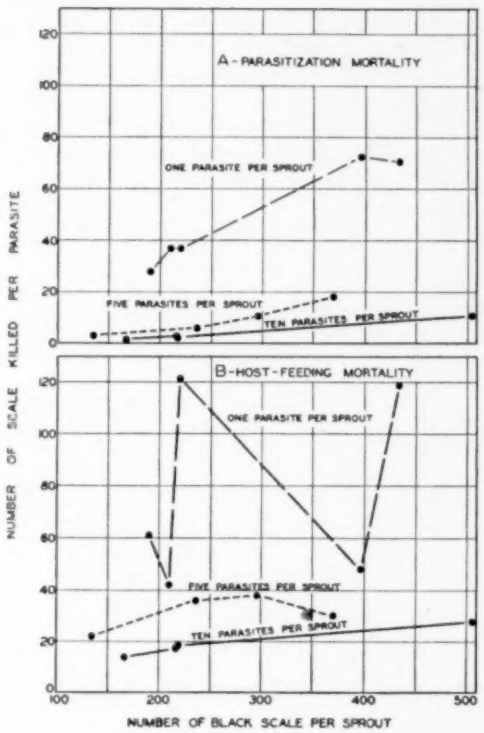

Fig. 3.—Relation between black-scale density per infested potato sprout and scale mortality per female *Metaphycus helvolus*, caused by parasitization (A) and by host-feeding (B) at the different parasite densities of 1, 5, or 10 adult females per sprout.

With 10 female parasites per sprout (Fig. 3, A), parasitization per female increases with host density still more slowly and is yet lower than that recorded in the

[1] This ignores eggs which may not mature because of superparasitization or excessive host-feeding by parasites.

curve for 5 females per sprout. In fact it is apparent that, with a host density much lower than that used (166), parasitization per female would approach zero.

To insure optimum production of parasites from a minimum amount of material, the most favorable parasite and host densities must be known. Deviation on either side will result in the unnecessary production of more hosts, or in a decrease in the number of parasites reared. Early in the work of rearing *Metaphycus helvolus* in the laboratory, for instance, some cages failed to produce parasites, although much "stinging" had been observed. This was undoubtedly caused by a superabundance of parasites.

The present data indicate that one female parasite per sprout is best, up to a host density of 300; five parasites per sprout then yield a greater total progeny, up to probably the largest host population feasible on a single sprout. Ten female parasites should not be used, because fewer total progeny are obtained and many of the original parasites are wasted. Gradations between one and five females were not obtained in the present studies. In actual insectary practice prior to these studies, three parasites per heavily infested potato sprout (300+ scales) was established empirically as the best number.

Figure 3, B, illustrates the effects of different numbers of parasite females per sprout upon host-feeding, per female, at different host densities. Regardless of black-scale density, host-feeding per female parasite is always greatest with one female per sprout, next greatest with five females per sprout, and smallest with 10 females per sprout. In each case there is a slight increase in host-feeding with increase in host density, but not nearly that found for parasitization. Host-feeding does not increase sharply with density, because, as previously mentioned, at the lower host densities, feeding is favored at the expense of parasitization. Host-feeding per female is, in all categories (1, 5, and 10 parasites per sprout), again seen to be higher than parasitization, although the curves tend to approach at high densities.

Thus far, of the three factors influencing the relation between parasitization and host-feeding mortality, two—parasite population density and host population density—have been analyzed. A discussion of the remaining factor, scale size, follows.

Table 5.—Change in scale size during one generation of the parasite *Metaphycus helvolus* (Comp.) (13 days at 80° F.), and size of scale parasitized.

Scale Size Group	Black Scale at Time of Parasite Oviposition			Black Scale at Time of Parasite Emergence				
	Age of Scale, Days	Live Scale (Size in mm.)		Age of Scale, Days	Live Scale (Size in mm.)		Parasitized Scale (Size in mm.)	
		Range	Average		Range	Average	Range	Average
Small	6	0.3–0.6	0.4	19	0.4–0.9	0.7	0.4–0.8	0.6
Medium	20	0.5–0.9	0.7	33	0.7–1.3	1.0	0.7–1.1	0.9
Large	53	1.0–2.7	1.6	66[1]	1.6–5.0	3.0	1.3–1.9	1.7

[1] Of the live scales in this group, 25 per cent had developed mature eggs.

Effect of Host Size.—Experiments dealing with the effect of size (or age) of black scale on mortality caused by parasitization and host-feeding by *Metaphycus helvolus* were set up in large insect-proof collection chambers about 3×2×2 ft. in size, at 80° F. Black scales of three age or size groups were used (Table 5). Infestations were on individual potted potato sprouts. The small-sized scales were nearly all too small for successful parasitization. The medium-sized scales were probably somewhat below the optimum size for parasitization. Some of the large-sized scales were too large for parasitization, since many were in the rubber stage, or close to it; however, probably 50 per cent of the scales were of an optimum size.

Five replicate potato sprouts of each of the three scale-size groups were put in separate collection chambers. Five females of *Metaphycus helvolus* were liberated per sprout (25 per chamber). It was felt that the host-density effect of individual sprouts could be eliminated by this

Table 6.—Relation between black-scale size and black-scale mortality caused by parasitization and host-feeding by *Metaphycus helvolus* (Comp.). (One parasite generation.)

Scale Size and Potato Sprout No.	Number, Scales Per Sprout		Scales Killed by Parasites		
			Total[1]	By Parasitization	Host-Feeding of Adults
	Initial	Final	Number	Per Cent	Per Cent
Experimental[2]					
Small					
1	425	148	277	5	60
2	513	390	123	5	19
3	536	463	73	4	10
4	662	485	177	5	21
5	668	306	362	5	49
Total or *Average*	2804	1792	1012	5	31
Medium					
1	184	111	73	33	7
2	430	222	208	17	31
3	518	272	246	22	25
4	631	430	201	34	−2
5	886	581	305	20	14
Total or *Average*	2649	1616	1033	24	15
Large					
1	179	35	144	46	35
2	195	53	142	41	32
3	261	97	164	32	31
4	271	104	167	21	41
5	301	122	179	25	35
Total or *Average*	1207	411	796	31	35
Control (No Parasites)					
Small					
1	613	595	18	0	0
2	578	545	33	0	0
Total or *Average*	1191	1140	51	0	0
Medium					
1	589	583	6	0	0
2	462	540	−78	0	0
Total or *Average*	1051	1123	−72	0	0
Large					
1	216	218	−2	0	0

[1] Control tests show no significant natural mortality; therefore no corrections for such are made.
[2] Twenty-five female parasites were used for each group of five sprouts.

procedure, since females of *M. helvolus* are very active and move freely from sprout to sprout. This results in an average for the five sprouts. Two sprouts of each group were kept as controls, in a separate chamber, with no *M. helvolus*.

These experiments were run for one parasite generation, that is, until the first progeny (males) of the original females emerged, a total of 13 days. Final counts were made at that time.

Measurements of the three size groups, made at the beginning and at the end of the test period, show the minimum, maximum, and average sizes of live scale and of parasitized scale. (The immature parasites in these scales were, in all cases, in the pupal stage.) These data are given in

table 5 and are of interest in showing the probable minimum and maximum sizes of parasitized scales in the field. The smallest scale parasitized (0.4 mm.) was barely larger than a newly settled crawler; the upper size limit of scale parasitized was approximately 2 mm.

The results of the tests of the effect of host size on mortality caused by parasitization and host-feeding are recorded in table 6 and are illustrated graphically in figure 4. A critical analysis of the

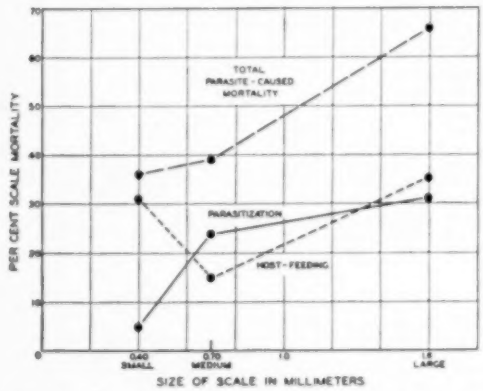

FIG. 4.—Relation between size of black scale on infested potato sprouts and per cent scale mortality caused by *Metaphycus helvolus*, expressed as total parasite-caused mortality, parasitization, and host-feeding mortality. Five sprouts and 25 parasites were used for each scale size (small, medium, and large).

differences in scale population density between individual sprouts and between size groups fails to show any significant connection between host density and mortality. In the case of the large-sized scale group, it would appear offhand that, because the group population was only about half that of the other two groups, they might not be comparable. Probably, however, because of the larger size of the scale, the population density is similar, since the scale surface per unit area is about the same, and the parasite has, therefore, to travel about the same distance between scales as with the smaller sizes.

Most evident and easily explained is the curve for per cent total parasite-caused mortality, in figure 4. Obviously, as the scale size increases, from a point which is too small for parasitization and therefore probably somewhat undesirable to the parasite, to a point at which the scale is of an optimum size for parasitization and host-feeding, an increase in per cent mortality, as illustrated, would be expected.

The curve for per cent parasitization is of the same type as that for total parasite-caused mortality. The small-sized scales are nearly all too small for parasitization, so that per cent parasitization is very low (5 per cent). The medium-sized scale, however, is very acceptable for parasitization, and per cent parasitization increases sharply to 24 per cent. The next scale size (large), being even more acceptable for parasitization, results in a further though more gradual increase in per cent parasitization, to 31 per cent.

The host-feeding mortality curve is somewhat more difficult to explain. The 31 per cent host-feeding mortality occurring with small-sized scales is logical enough, since nearly all these scales are too small for parasitization. The parasite is able to insert its ovipositor in a young scale and subject it to the mutilating probing process, preparatory to feeding, with much less effort than in larger scales; hence a high mortality may result from mutilation of young scales. According to Flanders, much of this mutilation may take place without feeding. This would help to explain why host-feeding mortality drops sharply to 15 per cent in the medium-sized scale. We may be dealing also with an experimental error, since one control test with medium-sized scales showed an apparent gain of 78 scales from an original 462, during the period of the tests. A similar increase occurred in one of the experimental tests with medium-sized scales. An increase of this sort tends to reduce the apparent host-feeding mortality.

This counting difference, although not serious, applies only to the medium-sized scales, which were counted with 2×-head binoculars. This magnification, for this size of scale, apparently was not always sufficient to distinguish between live and dead scales on the initial count. Sick or odd-looking scales were, as a result, usually counted as dead; but if they lived, they were much larger and more easily distinguished by the time of the next count. Their inclusion in the second count would therefore either increase the total number of live scales or replace scales which had been killed by feeding. This is

because counts were of live and parasitized scales only, the difference in mortality between total dead scales and parasitized scales being host-feeding mortality. No significant natural mortality occurred in these tests; hence corrections are not necessary. The small-sized scales were counted, both at the beginning and at the end of the test period, under a binocular microscope; the large-sized scales were of sufficient size to be easily counted with a head binocular.

Another reason for the relatively low host-feeding mortality occurring in the medium-sized scale group may be that these scales are in such physiological condition as to satisfy more readily the parasite's nutritional needs. In any case, the drop in host-feeding mortality is too great to be ascribed to counting errors alone.

The 35 per cent host-feeding mortality occurring in the large-sized scale group is more typical. Here, host-feeding mortality is greater than parasitization, as is usually the case. Both host-feeding mortality and parasitization reach their maximum values with the large-sized scale group, perhaps because the increase in egg deposition increases the nutritive requirements of the parasite.

SUMMARY.—Host-feeding, or host predatism, by the adult females, is known to be fairly common among the parasitic Hymenoptera. That its quantitative importance in the reduction of host populations may be as great as that of parasitization, or greater, is emphasized by the present findings.

Adult females of the parasite *Metaphycus helvolus* (Comp.) kill black scale, *Saissetia oleae* (Bern.), by parasitization, by mutilation with the ovipositor, and by host-feeding at ovipositor wounds. Field tests show that approximately 70 to 97 per cent of a black-scale infestation may be killed by *M. helvolus* over a period of several months. About 20 to 25 per cent of this mortality is caused by parasitization; the rest is attributed to host-feeding. The relative importance of host-feeding is highest during the early phases of an infestation, whereas that of parasitization is higher later, as the scale increases in size.

Laboratory tests, each involving one parasite generation, show that, within limits, per cent parasitization of scale is not markedly affected by parasite numbers. The percentage of scale killed by host-feeding is affected by parasite numbers, however, and follows a general upward trend as the parasite density increases. Total host-feeding mortality is much greater than parasitization mortality.

Per cent parasitization increases with host density at parasite densities of 1, 5, and 10 females per scale-infested potato sprout, whereas per cent host-feeding mortality decreases. Host-feeding mortality is the greater in all cases and increases, with respect to parasitization, at the higher parasite densities.

Parasitized scales, per female parasite generation, increase as host density increases. Parasite fertility is highest with 1 female parasite per scale-infested potato sprout, and, because of the limitation of the egg-laying capacity, reaches a maximum of 70 progeny at a host density of about 400 scales. Fertility is much lower at parasite densities of 5 and 10 females per sprout, probably because of competition between female parasites.

Host-feeding, per female parasite, increases slightly as host density increases, although not so rapidly as parasitization. Host-feeding mortality, per female parasite, is greatest with one parasite per sprout, less with five parasites per sprout, and least with 10 parasites per sprout. In every case host-feeding is greater than parasitization.

In general, as scale size increases, total parasite-caused mortality increases. Per cent parasitization increases rapidly from very small scales to medium-sized scales, and then increases more slowly from medium-sized to large-sized scales. Per cent host-feeding mortality decreases from small scales to medium-sized scales, and then increases with large-sized scales. Per cent host-feeding mortality is much greater than per cent parasitization at the small scale size, slightly greater at the large scale size, but somewhat less at the medium scale size.

These studies indicate that scales may be parasitized between the limits of 0.4 and 2.0 mm. in length.[1]—5-17-43.

[1] ACKNOWLEDGMENT.—Grateful acknowledgment is made to Professor Harry S. Smith for suggesting the problem, for his direction and advice throughout the course of the work, and for reviewing the manuscript. Thanks are similarly due to Mr. A. J. Basinger for his co-operation in gathering the field data; to Dr. Stanley E. Flanders for constant helpful advice, and for reviewing the manuscript; to Mr. Glenn L. Finney for preparation of the graphs, and for assisting in field counts; and to other members of the staff for their helpful advice and criticism.—5-17-43.

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Toxic-Dust Barriers for Chinch Bug Control[1]

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The shortage of creosote during the war emergency and the need for a suitable substitute to be used in chinch bug barrier construction provided the incentive for greatly expanded studies on the use of toxic-dust barriers which have been under way since 1939. In 1939 Decker & Drake (1940) while studying the effect of dinitro dusts on grasshoppers and other insects tested 3-5-dinitro-o-cresol on chinch bugs and found it to be a promising material both as a dust for destroying bugs on the base of corn plants and as a toxic-dust barrier material. At that time, it did not appear that toxic-dust barriers could compete in price with an abundant supply of creosote and the project was carried forward on a small scale. The shortage of creosote which developed in 1941 led to an expansion of both field and laboratory studies in 1942.

Barriers were constructed in the field with dusts containing 2, 4, 8 and 12 per cent of 3-5-dinitro-o-cresol, dinitro-o-secondary butyl phenol and dinitro-o-cyclohexyl phenol in pyrophyllite, both with and without the addition of 5 per cent mineral oil. Since no simple method of quantitatively checking the effectiveness of these barriers in the field was available, the results are limited to the impressions obtained by many observations on activity along the barrier line, the number of dead bugs under clods adjacent to the barrier and the number of bugs on the corn plants behind the barrier. In all cases, the barriers were highly effective in preventing the migrating bugs from reaching the corn. Since barrier failures were usually caused by rain or wind and all barriers were affected, it appears that the three compounds used are equally effective as barrier materials and that the 2 and 4 per cent dusts are about as effective as 8 and 12 per cent dusts.

In an attempt to obtain quantitative data, a series of the 24 (4 concentrations of three compounds with and without oil) toxic-dust barrier lines (approximately an inch wide) were constructed in the form of circles three feet in diameter and surrounded by concentric creosote barrier lines six feet in diameter. Thousands of fifth instar and adult chinch bugs were placed in the center of each circle. Two hours later there were many more live bugs between the dust and creosote barriers where the dinitro-o-cyclohexyl phenol was used showing the slower action of this dust. At the end of 5 hours, however, all of the bugs except a few which remained under clods in the central area were dead in all 24 plots. This seems to confirm the conclusion that the three dusts at the 4 different concentrations are about equally effective.

To determine the required rate of application, barriers were constructed using 8 per cent dinitro-o-cresol at the rate of one-fourth, one-half and one pound per rod. Carefully and properly constructed, all of these barriers were effective. While the lighter lines were more easily de-

[1] Journal paper No. J-1117 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 420.

stroyed by wind, it was noted that the lightest line (4 ounces per rod) would remain effective for several days if the maximum wind velocity did not exceed 15 miles per hour. At wind velocity above 15 miles per hour all dust lines were affected. Naturally the lighter lines were destroyed first. Dusts containing 5 per cent oil were slightly more wind-resistant than those without oil. Since all of the dust lines were subject to serious damage, if not complete destruction, by heavy rains that resulted in washing and since in western Iowa such rains occurred on 17 days between June 15 and July 31, it would seem that light lines (4 ounces per rod) should be used and the rest of the dust conserved to make repeated applications as needed. On two different occasions during the first half of July heavy rains made it necessary for some farmers to rebuild all barriers on three consecutive days. Although this was an exceptional condition, it should be noted that good machine-laid paper barriers stood up through five of the six rains in question, and required only slight repairs and the usual re-application of creosote.

FARM TESTS.—The U. S. Bureau of Entomology and Plant Quarantine provided 2000 pounds of dust containing 8 per cent 3-5-dinitro-o-cresol, 5 per cent oil and 87 per cent pyrophyllite which was distributed to farmers for field tests.

Fifteen individual farmers in widely separated parts of the infested area were provided with this dust and instructions for its use. These farmers built and maintained their own barriers.

Two farmers used 100 pounds in constructing 80 rods of barrier and by the end of the week had to resort to creosote for replacement. Two found 100 pounds adequate for one and one-half applications. Six obtained 2 complete applications, four made 3 complete applications and one farmer made 4 applications. All were 80-rod barriers. Four of the 15 ran out of material and had to use creosote before the end of the migration.

One farmer preferred dinitro dust, two to one, over creosote. Three farmers would prefer to use dinitro dust. Five would prefer dinitro if it cost no more than creosote. One would prefer creosote. Five were undecided as to whether they would use creosote or dinitro.

Although most of the farmers had dinitro dust with 5 per cent oil added, two used the dust, both with and without oil. These two agreed that, with the sprinkling can method, better lines could be laid more quickly with the dust without oil and the barriers were just as effective. Because the bugs are more quickly killed in contact with the dry dust, one of the farmers felt that the dust without oil was much superior to the oil impregnated dust.

Table 1.—Mortality of adult and 5th instar chinch bugs at intervals after walking through a 1-inch band of toxic dust.[1]

CONCENTRATIONS	5TH STAR			ADULT		
	3 hrs.	6 hrs.	24 hrs.	3 hrs.	6 hrs.	24 hrs.
	Dinitro-o-secondary butyl phenol					
Per cent						
1	29	43	67	47	65	88
2	30	50	80	50	85	96
4	48	75	92	70	87	100
8	93	100	100	96	100	100
	Dinitro-o-cyclohexyl phenol					
1	7	11	33	10	26	45
2	13	25	60	19	50	75
4	50	76	97	66	86	100
8	80	98	100	87	99	100
	Dinitro-o-cresol					
1	6	12	33	8	27	45
2	20	26	48	36	56	82
4	40	50	70	70	82	98
8	94	100	100	96	100	100

[1] In each experiment 400 bugs (8 lots of 50 each) were used.

LABORATORY STUDIES.—To obtain data on the lower limits of dilution that might be practical in making toxic dusts, 1, 2, 4 and 8 per cent dusts of 3-5-dinitro-o-cresol, dinitro-o-cyclohexyl phenol and dinitro-o-secondary butylphenol were prepared and dusted in a bell jar having flour masks which left a ring of dust one inch wide, dusted at the rate of 5 mg. per sq. in. (appr. 60 pounds per acre). Chinch bugs released inside the ring were collected after they had walked through the dust and the mortality was recorded at regular intervals. The results obtained are shown in table 1. Since there was great variation in the amount of dust that adhered to the bodies of the insects in repeated tests, the data were quite variable. Although analysis of variance showed that at the 1 and 2 per cent concentrations, dusts of dinitro-o-secondary butylphenol were significantly more toxic than those of dinitro-o-cresol, the question of relative toxicity can best be studied by another technique. The data are presented here to show that all three materials are so toxic that a large percentage of the bugs that merely walked across the very thin layer of dilute dust were killed.

To limit the degree of variability noted in the preceding experiment lots of 50 (25 adult and 25 fifth instar) chinch bugs were placed in a vial containing 1 per cent dusts of dinitro-o-secondary butylphenol, 3-5-dinitro-o-cresol and dinitro-o-cyclohexyl phenol and shaken for 10 seconds after which they were placed in fine wire screen cages and the surplus dust removed by jarring. The mortality at intervals after dusting is shown in table 2. The

Table 2.—Percentage of adult and 5th instar chinch bugs dead at intervals after dusting with 1 per cent dust of various compounds.

No. of Insects Used	Minutes after Treatment											
	10	15	20	25	30	35	40	50	60	70	80	100
	Dinitro-o-secondary butyl phenol											
400	30*	76†	90	94	98	99	100					
	3-5-Dinitro-o-Cresol											
400	30*	62†	76	86	90	92	96		100			
	Dinitro-o-cyclohexyl phenol											
200			10		30			50	74	84	92	98	100

* Highly significant difference (P = 0.01).
† Significant difference (P = 0.05).

data show that all bugs that are well covered with a 1 per cent dust of any of the three dinitro compounds tested will die within 2 hours. Dinitro-o-cyclohexyl phenol is definitely slower in its action than the other two compounds. A study of the data by analysis of variance, however, shows that the difference in favor of the dinitro-o-secondary butyl phenol over dinitro-o-cresol is highly significant at 10 minutes and significant at 15 minutes. The differences at later intervals were not analyzed.

By the same method (shaking in dust and removing the surplus) the three dinitro compounds being studied and several of their salts were tested to determine their relative toxicity as 8 per cent dusts in pyrophyllite. The results presented in table 3 show that the ammonium salts are almost as toxic as the original compounds and that all of the salts tried were highly toxic. As a matter of fact, in this and all of the preceding experiments all of the materials used killed all of the insects within a few hours and the only difference noted is in the speed of action. It would appear, therefore, that any one of these compounds might be successfully used as a barrier material and that market price as well as speed of action should be considered in the final selection of a dust to be used in barrier construction.

DISCUSSION.—The field tests and farmers' experience with dinitro dust barriers for chinch bug control prove rather conclusively that such toxic dust barriers can be successfully used, but, like the creosote line and paper-fence barriers, they have certain disadvantages as well as advantages.

Under average field conditions 100 pounds of 8 per cent dinitro dust will not go as far as 50 gallons of creosote which at current prices means doubling the cost of materials. This is offset in part by the reduced cost of barrier construction.

Table 3.—Mortality of adult and 5th instar chinch bugs at intervals after thorough dusting with 8 per cent dusts of various chemicals in pyrophyllite.[1]

Chemicals Tested	Hours after Treatment					
	¼	½	1	2	4	6
Dinitro-o-secondary butyl phenol	86	100				
Dinitro-o-cresol	86	100				
Ammonium salt of Dinitro-secondary butyl phenol	30	88	100			
Ammonium salt of Dinitro-o-cresol	19	78	100			
2-4-Dinitro phenol	10	48	100			
Dinitro-o-cyclohexyl phenol	32	60	98	100		
Sodium salt of Dinitro-o-cresol			33	86	100	
Ammonium salt of Dinitro-o-cyclohexyl phenol			24	80	100	
Dicyclohexylamine salt of Dinitro-o-secondary butyl phenol			13	70	100	
Dicyclohexylamine salt of Dinitro-o-cresol			33	66	100	
Sodium salt of Dinitro-o-cyclohexyl phenol			3	26	70	100
-Dicyclohexylamine salt of Dinitro-o-cyclohexyl phenol			0	30	72	90
Pyrophyllite (100%)			0	2	6	14
Check				0	2	4

[1] In each experiment 250 bugs (5 lots of 50 each) were used.

Although extremely heavy rains may destroy both toxic-dust and creosote paper-fence barriers, most farmers observed that good paper-fence barriers withstood washing much better than the dust barriers. Wind also is a factor in determining the efficiency of the barriers. Gusty winds of eight miles per hour or higher, which are very common during the migration season, will carry many bugs across the dust barrier without injury to the bugs.

Farmers, whose experience with creosote came from hand-built paper-fence barriers, were more enthusiastic about the dinitro dust than those who have operated the mechanical paper-laying machines for the past three seasons.

The relatively high toxicity which has been demonstrated for several of the dinitro creosol and phenol compounds indicates the need for further study with this whole series of compounds. The dinitro-o-secondary butyl phenol is particularly promising since it proved to be decidedly more toxic than any of the other compounds tested. This seems to be due to the fact that the dinitro-o-secondary butyl phenol dust adheres to the body of the insect more readily than the other dusts.

A simple home-made mechanical device for laying the dust line developed during the season should replace the laborious and rather unsatisfactory modified sprinkling can method of applying the dust.

The results obtained in the laboratory studies are in close agreement with those obtained by Tauber and associates (unpublished) in a parallel but independent study.

OTHER USES OF DUST.—All of the toxic dusts studied proved to be highly effective as killing agents when applied to kill bugs in post holes used as traps in front of creosote barriers. Furthermore, it was found that a thin layer of dust on the ground in front of the barrier could be substituted for post holes but piles of dust at intervals along the line were not effective. Such piles interfered with the forward march of the bugs and resulted in stampeded bugs crossing the creosote line without coming in contact with the dust.

Table 4.—The degree of injury observed 96 hours after dusts containing 8 per cent of various chemicals in pyrophyllite were applied on plants.

TREATMENT EIGHT % IN PYROPHYLLITE	DEGREE OF BURNING		
	Base of large corn stalks	Seedling Plants	
		Corn	Oats
Dinitro-o-secondary butyl phenol	Slight	Severe	Severe
Dinitro-o-cresol	Slight	Severe	Severe
Dinitro-o-cyclohexyl phenol	None	Moderate	Moderate
Ammonium salt of Dinitro-o-secondary butyl phenol	Slight	Moderate	Severe
Ammonium salt of Dinitro-o-cresol	Slight	Moderate	Severe
Ammonium salt of Dinitro-o-cyclohexyl phenol	None	None	None
Dicyclohexylamine salt of Dinitro-o-Secondary butyl phenol	None	Trace	None
Dicyclohexylamine salt of Dinitro-o-cresol	None	Trace	None
Dicyclohexylamine salt of Dinitro-o-cyclohexyl phenol	None	None	None
Sodium salt of Dinitro-o-cresol	Trace	Moderate	Slight
Sodium salt of Dinitro-o-cyclohexyl phenol	Trace	Moderate	Slight
2-4-Dinitro-phenol	Trace	Moderate	Slight

The dusts were also highly effective in killing bugs that had accumulated on the base of corn plants. All of the dusts studied were about equally effective for this purpose and none of them caused serious burning if only the base of the stalks were dusted. Where dust entered the throat of the growing plant and where young seedlings were dusted serious burning occurred in some cases. The results of test to determine plant tolerance to the various dusts are given in table 4.—5-14-43.

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DR. WILMON NEWELL

From Dr. John T. Creighton, of the University of Florida, comes news of the death of Dr. Wilmon Newell, Provost of Agriculture at the University of Florida. Dr. Newell's death followed an illness which had lasted for more than a year.

Dr. Newell was well known to entomologists having served as President of the American Association of Economic Entomologists in 1920 and having been, for many years, active and influential in its councils. In more recent years he has been so engaged in his administrative duties that his activities in entomology have been restricted but he never lost interest in the subject or in the Association.

Dr. Newell was born in Iowa in 1878 and trained at Iowa State College. He served, as an entomologist, in Georgia, Louisiana and Texas before going, in 1915, to Florida. Dr. Creighton well says that "In the passing of this great leader the science of entomology has lost one of its most eminent members and southern agriculture one of its greatest leaders."

A more extended account of the career of Dr. Newell will be printed in an early issue of the JOURNAL.

Effect of Host Plant on the Susceptibility of the Southern Armyworm to Calcium Arsenate

BASIL G. MARKOS and F. L. CAMPBELL,[1] *Department of Zoology and Entomology, The Ohio State University, Columbus*

During the past 15 years many median lethal doses have been determined for different stomach insecticides against different species of leaf-eating insects, chiefly lepidopterous larvae. Determinations published up to 1936 have been assembled by Hansberry and Richardson (1936). In their summary no mention is made of the species of leaves upon which the insecticides were fed to the insects. However, the MLD of a given insecticide for a polyphagous species may depend on the species of leaf upon which it is offered to the insects. Swingle (1939) has approached this question from the point of view of the effect of previous diet upon susceptibility.

In the present work it was decided to find out for a single species of insect and insecticide whether the MLD would be affected by the species of leaf upon which it was fed and, if so, whether any reasonable explanation could be given for observed differences in mortality produced by a given dose.

MATERIALS.—The southern armyworm, *Prodenia eridania* Cram., was chosen as the test insect because it thrives on many species of plants and is easy to rear in the laboratory throughout the year.

Of the several plants used in these experiments, rhubarb (*Rheum raponicum*) and hollyhock (*Althaea rosea* L.) were found outdoors. Soybean (Manchu type), squash (*Cucurbita maxima* Duchesne), Blue Hubbard variety, corn (*Zea mays* L.), yellow dent field corn, and cranberry bean (*Phaseolus*), horticultural variety, were grown in the greenhouse by the methods of Waters (1937). Kale was bought on a vegetable market.

The insecticide used was a zinc-safened basic calcium arsenate having the following composition:

CaO/As_2O_5	3.33 per cent or greater
As_2O_5	42.5 per cent
$ZnSO_4$	equivalent of 8 per cent (anhydrous)
Lime	very slight excess
Water soluble arsenic	0.2 per cent (Geneva method)
	0.75 per cent (Witman bubbler method)

DESIGN OF EXPERIMENTS.—In planning the experiments, the possible effect of diet on the insects previous to the susceptibility tests was not overlooked (Swingle 1939). A choice had to be made between rearing all insects on a single species of plant and then determining their susceptibility to the calcium arsenate on a number of different species of leaves, or rearing the insects on the various species of leaves upon which the susceptibility tests were to be made. It was decided to follow the latter course, because it was thought that a sudden transition from one species of leaf to another might interfere with feeding upon poisoned leaves. However, Swingle (1939) does not appear to have encountered this difficulty. From a practical point of view also, it seemed better to rear the insects on the species of leaves upon which the insecticide was to be applied, because in the field the insect is likely to complete its development upon one species and it is desirable to know whether one species of plant may require a heavier application of insecticide for control than another, other factors influencing effectiveness being equal.

The following plan of experimentation was not the best that could be devised, but represents the best feasible design under the circumstances of the investigation.

As a preliminary step the MLD of the insecticide was determined for early sixth instar larvae reared and dosed on a standard plant, cranberry bean. Then newly hatched larvae from a single egg mass were divided at random between the standard plant and another plant to be compared with it, and were reared to the early sixth instar. Twenty larvae were then taken at random from the popula-

[1] The writers are indebted to C. H. Richardson, Iowa State College, for constructive criticism of the original manuscript of this paper and to many of their associates for help and advice. Details of the investigation may be found in the senior author's Ph.D. dissertation deposited in the Ohio State University library.

tion on each plant within a certain range of insect weight. Each individual was fed the above mentioned MLD on a predetermined area of the species of leaf on which the insect had been reared. On different days these paired tests were repeated. The relative susceptibility of the insect to the insecticide on the two plants was based on relative per cent mortality. At later periods similar comparisons were made between other plants and the standard cranberry bean, using the MLD originally determined.

METHODS.—A new procedure[1] for the application of predetermined doses was developed: Leaf strips (one cm. wide) of leaf A and of the standard cranberry bean leaf were cut by a pair of razor blades, avoiding large veins. The upper surfaces of the leaf strips were coated with a sticker (Ellisor & Floyd 1939) by means of a camel's hair brush. While the leaf strips were slightly moist, masks were applied, exposing a rectangular area along the middle of the strip. Seven masked strips were then placed on a moistened aluminum plate of the same size as the aluminum weighing plate (50 sq. cm.).

The plate bearing the leaf strips and the weighed plate were placed in the drawer under a dusting cylinder. A known quantity of dust (0.150 g.) in a bent tube was blown up into the cylinder by means of a foot pump delivering a reproducible puff of air. The entire charge of dust was then allowed to settle upon the leaf strips and weighing plate on the base of the cylinder. A settling period of 10 minutes was allowed before the leaf strips and weighing plate were removed from the drawer. The dusted leaf strips were placed temporarily in a humidor and the other plate was reweighed to check the quantity of deposit expected.

The leaf strips were now ready to be cut into small pieces of a size calculated to bear the dose that was to be fed to each weighed larva. A leaf strip was removed from the humidor and the mask carefully pulled off. It was then trimmed on three sides as close to the dust as possible, leaving an undusted margin on one long side. By lining up the trimmed leaf strips against a metric scale, small pieces of leaf were cut off by means of a sharp razor blade into predetermined areas.

[1] See Waters (1943) for a description of improvements in this procedure and for illustrations of equipment used in it.

Table 1.—Effect of host plant on the susceptibility of the sixth instar southern armyworm to calcium arsenate. Dose 0.18 mg./gm.—the MLD on cranberry bean.

Host Plant	Number of Tests	Total Number of Insects	Per Cent Dead	t Test[1]
Rhubarb	5	100	83.0	7.9*
Cranberry bean	5	99	31.3	
Kale	4	74	72.9	1.9
Cranberry bean	4	72	80.5	
Hollyhock	7	126	42.8	2.7*
Cranberry bean	7	131	61.0	
Soybean	5	94	15.9	3.4*
Cranberry bean	5	93	52.6	
Corn	7	128	11.7	5.0**
Cranberry bean	7	128	67.9	
Squash	7	139	6.4	7.6**
Cranberry bean	7	138	60.0	

[1] Analysis based on per cent mortality transformed into angles of equivalent information.
* Significant.
** Highly significant.

Care was taken to make square cuts of the leaf strips and to prevent any disturbance of the dust. As each piece of leaf was cut off, an insect pin was thrust through its undusted margin, three-quarters of the distance to the head of the pin. The pin bearing the piece of leaf was then stuck in one end of a small cork stopper.

Each leaf mount was placed on moist sand in can covers. Upon the stopper of each mount was then placed a weighed larva that had had no food for one-half hour. The whole mount and larva were then enclosed within a tube (20 mm. diam.), the upper end of which was covered with a small piece of cheesecloth. This enclosure allows just enough room for the larvae to crawl upward on the pin and feed on the piece of leaf. Occasionally a larva would feed from the pin outward and cause the leaf to drop from the pin. The majority of the larvae, however, started from the outside edge of the leaf, away from the pin, and fed toward the pin, consuming the entire dusted area within one-half hour. The few larvae that did not consume the entire dose were discarded. When the larvae had consumed the leaf area, they crawled to the top of the tubes and remained on the cheesecloth until they were transferred to observation cages with fresh undusted leaves.

Observations on mortality were made at the end of 24 and 36 hours. If the insect did not succumb within 24 hours, it would usually survive. Those insects that did survive consumed all the fresh food placed at their disposal.

RESULTS.—Table 1 summarizes the results of feeding 0.18 mg./g. (the preliminary MLD) of the insecticide to each of the 1322 larvae used in the comparisons. From 4 to 7 tests were made for each pair of plants, generally using 40 larvae for each test. It is concluded that significant differences in susceptibility were demonstrated between certain pairs of plants under the particular conditions of the tests and that, therefore, it is not unreasonable to expect the MLD of a stomach insecticide for a polyphagous insect to depend in part on the species of leaf upon which the insecticide is offered to the insect.

Table 2.—Effect of oxalic acid on toxicity of calcium arsenate to the southern armyworm on cranberry bean.

MATERIALS	DOSAGE (MG./GM.)	NO. OF TESTS	TOTAL NO. OF INSECTS	PER CENT DEAD	t TEST[1]
Oxalic acid only (Check)	0.18	7	138	0	
Calcium arsenate	0.18	7	138	47.1	6.1[2]
Calcium arsenate plus oxalic acid	0.18	7	140	78.6	

[1] Analysis based on per cent mortality transformed into angles of equivalent information.
[2] Highly significant.

DISCUSSION AND ADDITIONAL EXPERIMENTS.—The work of the writer and of Swingle (1939) show that the food of the southern armyworm, past or present, may influence its susceptibility to an arsenical. If the previous diet is primarily responsible for the differences in susceptibility observed, the possibility of explaining such effects seems remote. If, however, it is assumed that the food ingested with the arsenical is directly responsible for the differences observed, then it is reasonable to seek explanations for these effects by experiments. Particular attention was given to an experimental study of an obvious chemical explanation for the apparent high susceptibility of the southern armyworm to calcium arsenate on rhubarb.

It is well known that rhubarb contains oxalic acid (Pucher *et al.* 1937), which might react with calcium arsenate in the gut of the insect to form the highly insoluble calcium oxalate with the liberation of soluble arsenic. Such was indicated by determinations of arsenic in the filtered juice from the gut of larvae poisoned with the same dose of insecticide on different leaves. Rhubarb liberated more soluble arsenic from the standard dose than did the other species of leaves. Although the juice of rhubarb is acid, its solvent action on calcium arsenate in the gut cannot be attributed to acidification of the gut contents, which are buffered and remain at a high pH value regardless of the pH of juice of the plant that is ingested (Swingle 1938).

If oxalic acid is responsible for the high susceptibility of the insect on rhubarb, it was reasoned that powdered oxalic acid added to the standard dose of calcium arsenate on cranberry bean should give a significantly higher mortality than the same dose of calcium arsenate alone. This hypothesis was borne out by the results given in table 2.

The foregoing results suggest the desirability of recording with each MLD for stomach insecticides the species of leaf upon which the insecticide was applied.

SUMMARY.—A method is described for feeding predetermined doses of powdered stomach insecticides to the early sixth instar of the southern armyworm, *Prodenia eridania* Cram.

The median lethal dose of a zinc-safened calcium arsenate to this insect, as determined by this method, was 0.18 mg./g. when the larvae were reared on cranberry bean and the arsenical was fed on this plant.

Other larvae were reared continually on cranberry bean and at different times on rhubarb, kale, hollyhock, soybean, squash and corn. In the early sixth instar individual larvae were fed the above MLD on the species of leaf upon which they had been reared. Paired comparisons of the effect of this dose on larvae from the same egg masses were made on rhubarb and cranberry bean, kale and cranberry bean, etc., always using cranberry bean as the standard of comparison with the other plants. Highly significant differences were found between the per cent mortality on cranberry bean and on rhubarb, squash and corn respectively. Thus it was demon-

strated for certain sets of conditions that the susceptibility of a leaf-eating insect to a stomach insecticide depends on its previous diet, or on the immediate effect of the species of leaf with which the poison is ingested, or both. Whatever may be the cause of the observed differences in susceptibility, it would be well in the future to record the host plant used for the determination of the MLD of stomach insecticides for leaf eating insects.

A clue was obtained to the high susceptibility of the larvae on rhubarb, reasoning and experimenting as follows: Rhubarb contains oxalic acid; powdered oxalic acid alone had no effect on the larvae; a mixture of calcium arsenate and oxalic acid on cranberry bean was more toxic than the same quantity of calcium arsenate alone; rhubarb liberated more water soluble arsenic from calcium arsenate in the gut than the other plants did. Therefore, the high susceptibility on rhubarb may be attributed to a reaction in the gut between oxalic acid or other acids and calcium arsenate, releasing a lethal dose of water soluble arsenic. Rhubarb, though highly acid, did not change the normal alkaline pH of the gut.—5-31-43.

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Alfalfa Butterfly Control with Sulphur Dusts[1,2,3]

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The alfalfa butterfly, *Colias eurytheme* Bdv. (Figs. 1 & 2), is the most important pest of alfalfa in the southwestern region of the United States. If it were not for the population control by a parasite, *Apanteles flaviconchae* Riley, and a wilt disease which frequently attacks the butterfly larvae, alfalfa could not be profitably grown during midsummer and fall in the warmer parts of this region (Michelbacher & Smith 1943). However, in spite of the effectiveness of these natural controls, the alfalfa butterfly larvae frequently do serious damage. Injury is most severe in the latter part of the summer from July to September when whole fields in the San Joaquin Valley are sometimes reduced to bare stems.

The problem of obtaining an insecticide to control this pest has been very difficult for several reasons; (1) the relatively low value of each single cutting of alfalfa, (2) the danger to livestock from application of the usual poisons to hay, (3) the danger to the parasite from the application of contact insecticides, (4) and until recently the lack of information regarding population trends and the interrelationships of the pest and its parasites and predators. Although alfalfa is one of the most valuable hay and forage crops produced in the United States, the amount of money that can be expended for insect control on any given cutting is very low. Moreover, growers often believe that loss from attack by butterfly larvae can be compensated

[1] The authors wish to express their appreciation to Dr. A. E. Michelbacher and Dr. L. R. Jeppson of this station for material aid received especially during the early stages of this investigation.

[2] Early publication of this paper has been secured by payment of the costs of printing.

[3] Presented at the Pacific Slope Branch Meetings, Corvallis, Oregon, 1943.

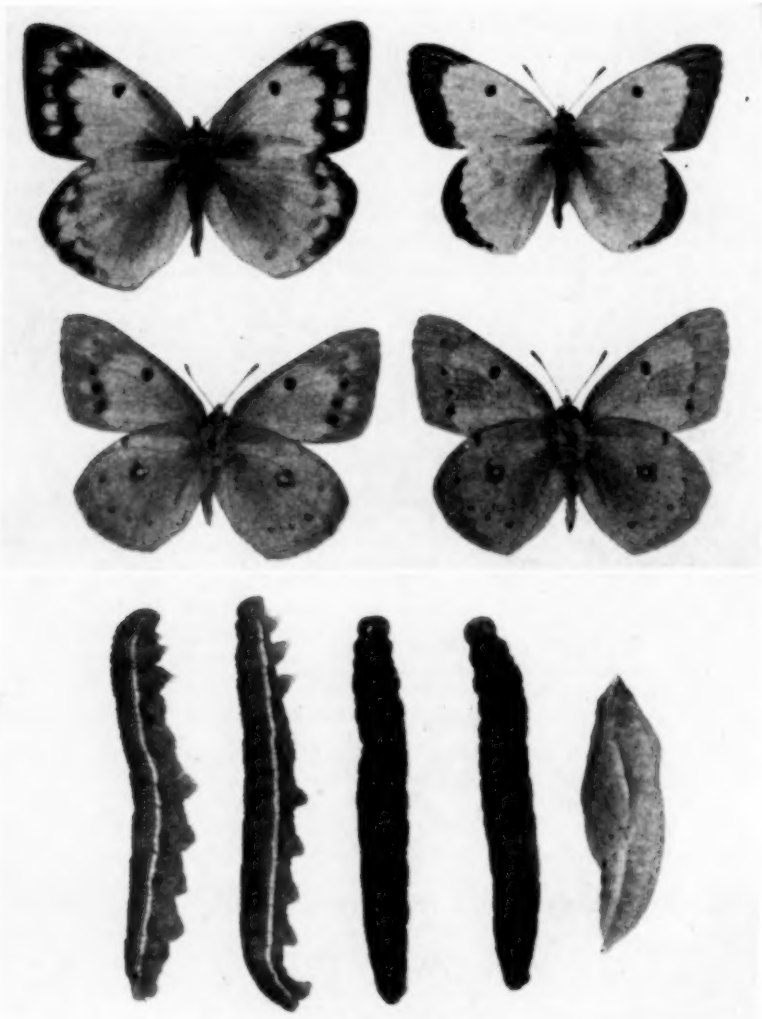

FIG. 1.—The alfalfa butterfly, *Colias eurytheme* Bdv., male and female above. Larvae and pupa below.

for in the succeeding crop. Arsenicals and fluorine compounds have sometimes been recommended in low dosages for the control of the alfalfa butterfly but because of the hazard to livestock their use is very limited. Contact insecticides, *e.g.* pyrethrum, have been ineffective or are too expensive. In addition to these considerations, experimental investigations are greatly hampered by great fluctuations in populations due to parasites, wilt disease, and weather conditions. It is the opinion of the authors that due to these complicating factors control has been ascribed incorrectly to various insecticides tested when perhaps wilt disease or parasites were responsible for reducing the number of worms. Practical control measures up until the present time have consisted of cultural procedures such as timely cutting to destroy the larvae, use of drags to crush the larvae, and irrigation to make conditions favorable for the wilt disease (Wildermuth 1920; Michelbacher & Smith 1943).

While making *Lygus* counts in an alfalfa experiment on Union Island in 1940, L. R. Jeppson of this station observed marked differences in the numbers of larvae of the alfalfa butterfly and other Lepidoptera.

This experiment was laid out as a 4 by 4 latin square with sulphur applied at different dosages. The dust was applied in three applications to the fifth crop of hay and counts were made on August 26, 1940. The results, which are summarized in table 1, show a three- to sixfold reduction directly paralleling the the amounts of sulphur—there being a decrease in the number of larvae as more and more sulphur was used. These reductions under the untreated check are all statistically significant. On the basis of all the data, the treatments are not different statistically from one another. However, if the check with its obviously large population of larvae is omitted from the calculations and the variance of the sulphur treated plots alone is calculated, there are significant differences in the larval populations in these test plots. By this procedure, it can be shown that there were fewer larvae in those plots treated with 100 and 200 pounds of dust per acre as compared with 50 pounds per acre. However, no additional reductions of larvae were secured by applying 200 pounds of dust as compared with 100 pounds per acre. These data suggested that it would be highly desirable to pursue this study further in an intensive and more complete manner. However, it was not until 1942 that this work was further expanded and additional data obtained.

Table 1.—The effect of sulphur dust on larvae of the alfalfa butterfly in a dosage experiment, Union Island, 1940.

	Pounds of 325 Mesh Dusting Sulphur Applied per Acre			
	0	50	100	200
Sample	Living Larvae per Plot			
1	121	71	47	22
2	190	43	41	33
3	98	36	28	36
4	177	28	19	27
Total	586	178	135	118

Analysis of Variance

Factor	S.S.	d.f.	V.	F.
Total	44,633.94	15		
Rows	1,500.69	3	500.23	1.25
Columns	3,569.19	3	1,189.73	2.97
Treatments	37,164.19	3	12,388.06	30.96
Error	2,399.87	6	399.98	

Differences in total numbers of worms of 138.30 are significant with odds of 19:1.

FIG. 2.—Larvae of alfalfa butterfly feeding on alfalfa.

Due to attacks by the wilt disease, satisfactory experimental conditions for tests with the alfalfa butterfly larvae did not occur in 1941. In the latter part of July, 1942, the proper conditions for a test developed and several experiments were conducted. On the morning of July 29, the following materials were applied with a *Root* row-crop duster attached to a *Farmall* tractor: (1) commercial dusting sulphur (95 per cent 325 mesh) at 30 pounds per acre; (2) commercial dusting sulphur (95 per cent 325 mesh) with 0.75 per cent arsenic trioxide at 30 pounds per acre; (3) 50 per cent commercial calcium arsenate—50 per cent dusting sulphur (95 per cent 325 mesh) at 13 pounds per acre. The dusting conditions were excellent with practically no drift and an abundance of dew. Each material was applied to plots 0.2 acre in area replicated four times in a "row"-type experiment. The sulphur with 0.75 per cent arsenic trioxide caused slight burning. No injury was caused by the other insecticides.

After about 30 hours, dead and sick larvae could be easily found in the sulphur dusted plots. However, counts made 7 days after dusting gave the results summarized in table 2. A preliminary count

Table 2.—Effect of sulphur and arsenical dusts on alfalfa butterfly larvae applied on July 29, 1942.

Size of Worms	Dusting Sulphur[1] at 30 lbs. per Acre	50% Commercial Calcium Arsenate and 50% Dusting Sulphur[1] at 13 lbs. per Acre	Dusting Sulphur[1] with 0.75% As_2O_3 at 30 lbs. per Acre	Untreated
Large	191	157	194	244
Medium	142	43	59	71
Small	40	5	35	15
Total	373	205	288	330

Analysis of Variance

Factor	S.S.	d.f.	V.	F.
Total	24,067.96	47		
Whole unit	4,322.62	15		
Treatment	569.12	3	189.71	not significant
Error	3,753.50	12	312.79	
Insect size	14,863.84	2	7,431.92	62.57
Interaction:				
Insect size × Treatments	2,031.00	6	338.50	2.850[2]
Error	2,850.50	24	118.77	

Differences of 63.71 in total numbers of worms in any two size categories are significant with odds of 19:1.

[1] 95% 325 mesh.
[2] Significant at 0.05% level.

made 5 days after treatment showed 1267 larvae per 100 sweeps on untreated plants, 611 larvae on sulphur-arsenic trioxide, 826 larvae on sulphur-calcium arsenate, and 890 on sulphur treated plants. All the treatments thus had significantly fewer total larvae than the check plants. There were, however, no statistically significant differences between any of the treatments. Larval counts of over 500 large larvae per 100 sweeps of the insect net are liable to result in damage and since infestations of over 1500 large larvae per 100 sweeps are common neither of these reductions would give satisfactory control under practical field conditions. Moreover, the calcium arsenate-sulphur dust was applied at twice the recommended dosage for alfalfa weevil and the danger to livestock from poor or over applications would be serious. After 7 days, there were no notably different total numbers of larvae on plants in plots treated with the various materials.

However, there were other differences which were significant: There were fewer small larvae than large, in all plots. It is interesting to note that the differences between small and large larvae are very consistent for all treatments and much smaller than the difference in the case of untreated plants. This is probably explained by the fact that all of the treated plants had fewer large larvae than the untreated plants. The differences between numbers of medium-sized larvae and either large or small larvae are also very suggestive. In the case of the sulphur dust, there were many more medium-sized larvae than small larvae and the difference was statistically significant. In considering these medium-sized larvae, it is apparent that there were increased numbers of large, as compared with medium-sized larvae, in the case of the untreated plots. It is also apparent that there were sig, nificantly more medium-sized larvae in the sulphur treated than there were in either of the other treatments or the untreated plot.

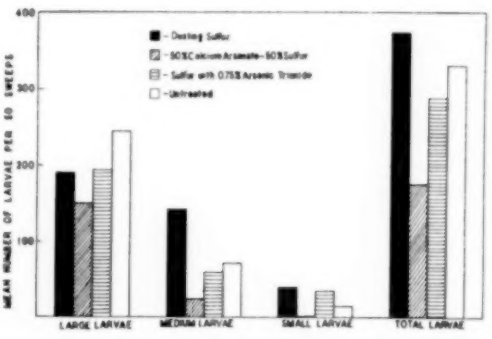

FIG. 3.—Comparative numbers of alfalfa butterfly larvae in terms of size of worms, August 4, 1942. Note disproportionate number of medium-sized larvae in sulphur treatment.

Graphic analysis of the data as shown in figure 3 affords an explanation of this apparent discrepancy. The sulphur plots contain an abnormal proportion of medium-sized larvae. In the light of additional results, this can be explained as follows: 30 pounds of sulphur per acre is a sublethal dose. A few larvae (30 per cent in this case) are killed but most of them are only made ill. Their symptoms are very characteristic. A slight amount of diarrhea is followed by constipation. They stop feeding and move rapidly over the

plants as contrasted to the quiet constant feeding of normal larvae. Since they stop feeding, their development is arrested and they soon shrink in size. Such a typically sulphur-affected fifth instar larva is contrasted diagrammatically in figure 4 with a normal larva. The head capsule, of

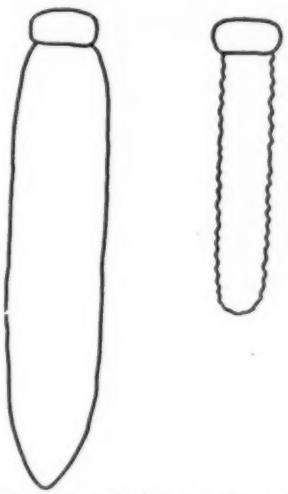

FIG. 4.—A diagrammatic drawing of a normal (left) and sulphur-treated (right) alfalfa butterfly fifth instar larvae. Note the size of head capsules and the shrunken body of sulphur-treated larva.

course, does not shrink and these characteristic "big-headed" larvae (as contrasted with normal larvae) are common in sulphur dusted plots. In the other plots, the populations are reduced by pupation and emergence. In the sulphur plots, pupation was greatly reduced and these "big-headed" shrunken larvae were classed as "medium-sized larvae." While total numbers of larvae in the sulphur plots are greater than in untreated plots, this can be accounted for by the sublethal dosage of sulphur which slowed down the rate of development. There was no total population decrease due to pupation and emergence.

Following the previous experiment, several small areas were dusted with sulphur. The results were so outstanding that immediately an extensive experiment was laid out for testing various kinds of sulphurs. All applications were at approximately 70 pounds per acre with a Root row-crop duster mounted on a *Farmall* tractor. Five days after the dusts were applied, each plot in the 4 replicates of each treatment was sampled by making

Table 3.—Numbers and sizes of alfalfa butterfly larvae in plots treated with different sulphur dusts.

SIZE OF WORMS	PRECIPITATED SULPHUR[1]	DUSTING SULPHUR[2]	DUSTING SULPHUR[3]	WETTABLE SULPHUR[4]	UNTREATED	TOTALS
Large	112	161	145	171	552	1141
Medium	93	73	86	87	190	529
Small	38	23	41	33	59	194
Total	243	257	272	291	811	1874

Analysis of Variance

Factor	S.S.	d.f.	V.	F.
Total	78,336.73	59		
Whole unit	24,842.73	19		
Treatment	19,925.73	4	4,981.43	15.197
Error	4,917.00	15	327.80	
Insect size	21,180.63	2	10,590.31	20.798
Interaction: Insect size X Treatment	17,037.87	8	2,129.73	4.183
Error	15,275.50	30	509.18	

Differences of 189.23 in total numbers of worms in any treatment are significant with odds of 19:1.

Differences of 127.64 worms between any 2 size categories are significant with odds of 19:1.

[1] A mining by-product containing 98–99% sulphur. Particle size 1.5 to 4 microns.
[2] A blend of (1) and finely ground (95% 325 mesh) sulphur. Minimum of 98% sulphur.
[3] A ground dusting sulphur containing 98–99% sulphur of 95% 325 mesh in fineness.
[4] A blend of (1) and finely ground (95% 325 mesh) sulphur with 5% wetting and dispersing agents. Minimum of 95% sulphur.

25 sweeps with a standard insect net. The larvae were classified as to size and condition as shown in table 3 and figure 5.

All of the sulphurs gave effective and statistically significant reductions in number of larvae as compared with the check. On the basis of total larvae, these sulphurs gave over 65 per cent reduction and on the basis of large larvae (the ones that do the greatest damage) the reduction was as high as 80 per cent. This would give satisfactory control under nearly all conditions. All of the treatments resulted in highly significant reductions in numbers of large worms on the plants while the

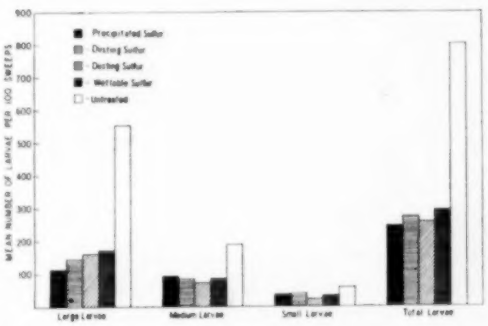

FIG. 5.—Relative number of alfalfa butterfly larvae classified as to size in plots dusted with different types of sulphur.

medium and small worms showed no statistically significant differences although the numbers were definitely fewer in the treated plots. It is equally obvious that there was a much higher proportion of large worms to medium or small worms in the check plots as contrasted with the treated plots. This increases the practical control making it actually better than 65 per cent reduction. These "big-headed" worms feed but little, if at all, and eventually die. The ratio of medium worms to total worms in the precipitated sulphur plot, for example, was 1:2.6 while in the checks the ratio was 1:4.2. This ratio was quite evident when the counts were being made. The checks were slightly reduced by wilt, no doubt due to the high population, while the treated plots had no wilt at the time the counts were made.

As far as can be determined MacLeod (1937) was the first to publish on sulphur as a stomach poison. In that work he obtained over 90 per cent control of the eastern tent caterpillar within 6 days with ordinary 325 mesh sulphur. Dickinson *et al.* (1941) have more recently shown sulphur to be lethal to the southern armyworm, *Prodenia eridania* (Cram.), the variegated cutworm, *Peridroma margaritosa* (Haw.), and the fall armyworm, *Laphygma frugiperda* (A. & S.). Apparently these are the only papers where the possibility of sulphur as a stomach poison for insects was recognized. However, there are numerous other references in the literature in which sulphur has been recommended for use either alone or in combination with some other insecticides for chewing insects. Roney & Thomas (1935a, 1935b) mention sulphur dusts as reducing populations of *Diabrotica balteata* Lec. and various cabbage worms, but they did not seem to attach particular significance to this fact. Sulphur has been reported to increase the toxicity of other insecticides in the case of tests with many insects, *e.g. Bombyx mori* larvae (Bulger 1932), *Anthonomus signatus* Say (Headlee 1916), plum curculio (Snapp & Thomson 1932) and others.

These increases in effectiveness may have been closely related to several factors —deposit, particle size, synergistic effects, or the action of sulphur itself. However, the frequent occurrence in the literature of reference to the increased toxicity of dusts containing sulphur is significant. Sulphur has also been used in combination with other materials against many chewing insects (achemon sphinx, *Pholus achemon* (Drury) and California grape root worm, *Adoxus obscurus* (Linn.), Essig & Hoskins 1934; cabbage worms, *Autographa brassicae* (Riley), *Pieris rapae* (L.), *Plutella maculipennis* (Curtis), and *Hellula undalis* (F.), Headlee, 1935, Fenton, 1936, White, 1935, Roney & Thomas, 1935; alfalfa weevil, *Hypera postica* (Gyll.), Newton, 1922; codling moth, *Carpocapsa pomonella* (L.) Smith 1926; Mexican bean beetle, *Epilachna varivestris* Muls., and strawberry root worm, *Paria canella* (F.), Metcalf & Flint, 1939). The basis for the use of sulphur dusts in all these cases is probably due largely to the cheapness of the material, fitness for application, and value in fungus disease control, but the effect of sulphur itself may have been overlooked.

The mode of action of sulphur in killing the alfalfa butterfly larvae is not known. The symptoms, which have been described above, seem to corroborate the theory of a "sulphur-plug" found in the gut. MacLeod (1937) observed what appeared to be a "plug" in radiographs taken with a grenz-ray tube. Dickinson *et al.* (1941) described similar symptoms and actually found definite sulphur crystals in the gut. They also describe discoloration of the malpighian tubules and gut which indicates that some other factor or factors are associated with the toxicity. Their observation that particle size is apparently important in toxicity is borne out by our field results where there was a direct correlation between particle size and mortality. (However, the differences were not statistically significant), the more finely divided materials giving better kill. This may be associated with deposit or with an increased sulphur area for action and is in line with recent work on other insecticides (Smith & Goodhue, 1942).

CONCLUSIONS.—Sulphur shows great promise as an insecticide for the control of the alfalfa butterfly. In cases where natural checks are not effective, excellent control may apparently be obtained by treating the alfalfa when it is 8 inches high with 325 mesh dusting sulphur at 75 pounds per acre. A good grade of finely divided dusting sulphur should be used for ease of application and better coverage. Damage usually occurs during the growth

period of the fourth and fifth hay crops in the San Joaquin Valley.

Sulphur is an almost ideal insecticide for use on alfalfa. There is no poisonous residue and, as far as we know, the sulphur does not affect either the parasite or wilt disease. Sulphur in the amounts recommended may also have some beneficial action as a soil amendment. It is a relatively cheap insecticide.

When sulphur is applied close to the time of harvest, balers have complained of sulphur hurting their eyes. The sulphur should be applied early enough to allow it to dissipate before cutting.

Further tests should be made on dosage, effect on the parasite, palatability of the hay, and timing of applications before definite recommendations can be made.—8-6-43.

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Nematode Parasites of the White-Fringed Beetles

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Some of the relationships between insects and nematodes constitute a phase of biological control which has received comparatively little attention. Nematodes asciated with insects are common, and the nature of their association is usually intriguing. It is probably the fact that most of them are so exceedingly small that has rendered them rather unattractive as study subjects. Perhaps it is only our ignorance of nematodes that prevents assigning them a more important place in the scheme of things.

Until a few years ago, species of the mermithid group, popularly called "hairworms" were probably the best known nematode parasites of insects. Some mermithids are remarkable for their extreme length, and are frequently found to cause serious mortality or sterility in a variety of orthopteran pests. More recently, considerable attention has been given to *Neoaplectana glaseri* Steiner, a native parasite of the Japanese beetle, *Popillia japonica* Newm., in New Jersey. A technique for artificially propagating this species on a mass-production basis has been devised, and it has been colonized

over much of the beetle-infested portions of New Jersey. Although it is too early to judge the results of the colonization program which has just been completed, a promising degree of control of the Japanese beetle has been reported from field plots.

In the fall of 1940, nematodes of the genus *Neoaplectana* were found in white-fringed beetles, *Pantomorus* (*Graphognathus*) spp., collected in Harrison County, Miss. Previous to this discovery no parasitic enemies had been reported from the United States, or from South America, the original home of the insects, although preliminary laboratory experiments with the Japanese beetle nematode parasite *N. glaseri* for the control of the white-fringed beetle, by H. C. Young and H. S. Hollingsworth at Florala, Ala., in 1939, had shown rather promising results. The similarity of these Mississippi worms to *N. glaseri* suggested that they, too, might be parasitic, and stimulated renewed interest, on the part of control and research officials of the Bureau of Entomology and Plant Quarantine, in the possibility of utilizing parasitic nematodes in the control of the white-fringed beetles. A co-operative project was therefore established by the Divisions of Domestic Plant Quarantines and Cereal and Forage Insect Investigations, the purpose of which was to search for possible nematode and other parasites, investigate their potentialities as control agents of the white-fringed beetles, and devise ways and means of utilizing them to the fullest advantage in case truly effective species were found.

By the end of 1942 some 50,000 white-fringed beetles had been examined for nematodes. Somewhat over half of these specimens came from Harrison County, Miss., where more than 2 per cent of the soil stages of white-fringed beetles have been found to contain parasitic nematodes. Insects have been examined for nematodes from all the major white-fringed beetle infestations, exclusive of those found late in the summer of 1942 in North Carolina.

It appears that there is a complex of species or varieties of *Neoaplectana* in the Gulf Coastal region. All that have been tested in the laboratory have proved to be parasitic in white-fringed beetles. At Long Beach, Miss., a single random sampling of 1000 square feet of beetle-infested soil showed that 24 per cent of the beetles were parasitized by these worms. Undetermined species of *Neoaplectana* have been taken at Florala and Monroeville, Ala., and Pensacola, Fla., but only in the Gulfport, Miss., area have they been found occurring naturally in appreciable numbers.

Native mermithids have been taken in white-fringed beetles at Long Beach and Hattiesburg, Miss., and Monroeville, Ala. At Hattiesburg a one per cent soil sample of an area of 2000 square feet yielded 410 white-fringed beetle larvae, of which 3.2 per cent were parasitized by mermithids. The generic name of *Hexamermis* has been determined for one of the mermithid parasites; the life histories of none of them are known at present.

Another nematode, not a mermithid, which is unlike and perhaps not even closely related to *Neoaplectana*, has been found at several points in the Gulfport area, at New Orleans, La., Monroeville, and Grand Bay, Ala., and Pensacola, Fla. This worm has not yet been successfully cultured on artificial media, but its development has been traced in the host insect and has been found to be like that of *Neoaplectana*. In the absence of a published name, this parasite of white-fringed beetles is referred to as number 41088.

The native forms of *Neoaplectana* do not seem to differ from *N. glaseri* so far as their relation to the host insect is concerned. One of these forms, which is known at present only as *Neoaplectana* 41035, can be cultured on artificial media in the laboratory and produced in large numbers by the same methods employed with the Japanese beetle nematode. Its life history has been studied in some detail, and is briefly as follows: The worms exist free in the soil only as ensheathed larvae. These are the infective forms of the parasite. They enter the host insect, presumably by way of mouth or anus, and penetrate to the body cavity, where they become successively preadults and adults. There are two sexes, and the females are ovoviviparous.

The host insect having died 2 or 3 days after becoming infected with the parasites, *Neoaplectana* multiplies in the cadaver until at length all available nourishment is exhausted. The integument of the host, which is all that now

remains, is a sac of ensheathed nematode larvae which are ready to break out into the soil and find a new host. If a new host is not available, the worms can remain alive in the soil for an indefinite period. The life cycle is completed in about a week at 72° F. More than a thousand infective-stage nematodes can be produced in a single, large white-fringed beetle grub. It is believed that only the soil stages of the beetle are subject to attack by *Neoaplectana*. Adult beetles have been observed to issue from the soil with nematodes in them. This suggests a possible above-ground method for the distribution of the worms.

The Japanese beetle nematode *Neoaplectana glaseri* was obtained from New Jersey in numbers sufficient for laboratory use early in 1941. It readily attacked *Pantomorus peregrinus* Buch. and *P. leucoloma* (Boh.), the two species of white-fringed beetle then known. Parallel experiments with *Neoaplectana* 41035 and *N. glaseri* showed that the two parasites, native and introduced, were capable of about the same degree of control of test insects. In laboratory tests with beetle larvae or pupae in which dosages of 1, 5, and 10 thousand nematodes per ounce of soil were used, mortality averaged 58, 78, and 91 per cent, respectively. In large flowerpot cages set in the soil out of doors, dosages of 15, 75, and 1500 nematodes per ounce of soil gave average mortalities of from 44 to 99 per cent. In these tests the period of exposure never exceeded 4 weeks; therefore, in some instances the total effectiveness of the nematodes may not have been measured.

The parasitic ability of *Neoaplectana* having been demonstrated in the laboratory and in flowerpot tests, it was desired to know what the worms could do under field conditions. To learn this, a series of colonization plots, each 1000 square feet in area, was established in soil infested with white-fringed beetles in Louisiana, Mississippi, Alabama, and Florida during the spring of 1942. Infective-stage nematodes were distributed over the plots at the rate of 25,000 per square foot. Half of the treated plots were inoculated with *Neoaplectana glaseri* and half with the native *N.* 41035. Treated and check plots were sampled before inoculation to determine the beetle population initially present, and the presence or absence of native parasitic nematodes. The first general sampling of plots is planned for April and May 1943. This sampling is expected to show whether the worms were successfully established in the various environments represented by the plots. *Neoaplectana* has already been recovered from half of the plots, the worms themselves having been filtered and sedimented out of small soil samples.

Since white-fringed beetles probably were introduced within comparatively recent years from another continent, it is evident that the native, parasitic nematodes have been subsisting on native insect hosts. The species of *Neoaplectana* in the Gulfport area have been taken in white grubs and various undetermined scarabaeid larvae, as well as in white-fringed beetles. They have been taken once in a pupa of the vegetable weevil, *Listroderes obliquus* Klug, an introduced pest of wider distribution than the white-fringed beetle. In the laboratory *Neoaplectana* attacks the vegetable weevil, an undetermined *Curculio*, *Pantomorus taeniatulus* (Berg), and the sweet potato weevil, *Cylas formicarius* var. *elegantulus* (Summers). *Neoaplectana* 41035 has been sent to New Jersey, where it is being propagated in the nematode laboratory near Trenton. Both in the laboratory and in field plots this species has been found to attack the Japanese beetle.

Space does not permit the discussion of the nematodes whose associations with white-fringed beetles are not very fully understood. Some of these worms may later be found important, others very probably will not. It is, furthermore, not possible to deal here with those bacterial and fungus diseases and predators which have been met with during the course of this work, or to do more than mention *Neoaplectana chresima* Steiner, another nematode parasite of the Japanese beetle which has been found to attack *Pantomorus peregrinus*. In conclusion, it is hoped that this brief report will serve to introduce, at least, some of the actual and potential nematode enemies of the white-fringed beetles.—5-17-43.

Species, Distribution, Flight, and Host Preferences of June Beetles, in Wisconsin

T. R. Chamberlin, C. L. Fluke, and J. A. Callenbach[1,2]

Purposes and Scope of the Investigation.—The purpose of the study reported herein was to learn which species of June beetles are more prevalent in Wisconsin, their flight habits, their host preferences, and the relative importance of the broods, in order to determine whether control is attainable by insecticidal treatment of their host plants or when such control is feasible. This study was part of a general investigation of June beetles and white grubs initiated at Madison, Wis., in 1935 and was a cooperative project of the Division of Cereal and Forage Insect Investigations of the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, and the Wisconsin Agricultural Experiment Station through its Department of Economic Entomology. The period covered began with the flight of brood A beetles in 1935 and ended with the flight of brood A beetles in 1941, thus covering three A brood flights and two flights of both B and C broods.

Methods.—Most of the groves in which beetle flights were studied were selected early in the investigations, and collections were made from many of them each year throughout the whole period. A few of the original groves were abandoned for various reasons. The groves were favorably located with respect to pasture and other land in which grubs could mature and contained as large a number of the species of shrubs and trees characteristic of the locality as possible. Groves consisting largely of single species of plants were avoided, even if it were known that these plants were favorite hosts of some species of June beetles.

Except in a few cases early in the investigations, when some beetles were shaken from host plants onto a canvas, all beetles were collected by hand at night. From two to four collectors usually worked in each grove with flashlights, using throughout the experiments the ordinary type of flashlight of good quality. In most instances collectors were present at the grove before the beetles began to emerge. The time, as well as the air and soil temperatures at which the flight began, was ascertained. Temperatures were also taken at various other times, especially when the main flight ended, the collection ceased, and individual species began or ceased to emerge. Observations on wind and precipitation were also made.

Collectors entered a grove and followed various courses, removing all beetles within reach from all host plants encountered. In some instances it was impossible to remove all beetles from a single kind of plant without neglecting others. Generally speaking, however, this was rare in the groves selected for study, because heaviest concentration of beetles on individual species of plants ordinarily does not occur in mixed plantings but rather in small isolated clumps of trees chiefly of single species, such as bur oaks or hickories. When such a concentration was encountered in a grove, fair samples were taken from the more heavily infested plants and the others were examined as usual. Herbaceous plants, as well as shrubs and trees, were examined.[3]

The time spent in the different groves varied with the flight activities of the beetles. If the flights were light, the time spent was, generally speaking, from 7:30 or 8 P.M. to 10 P.M., and if they were good, from 7:30 or 8 P.M. to 11 or 11:30 P.M.

Beetles collected were placed in wide-mouthed bottles of various sizes with screw tops, each of which bore the name of a single host plant. The bottles were carried in specially made canvas aprons with pockets to fit three sizes of bottles. Beetles were determined in the laboratory, usually on the day following the collection.

In the seven years 1935 to 1941, inclusive, observations were made in 28

[1] Chamberlin, U. S. Bureau of Entomology and Plant Quarantine; Fluke, Wisconsin Agricultural Experiment Station; Callenbach, U. S. Bureau of Entomology and Plant Quarantine and the Wisconsin Agricultural Experiment Station. Callenbach made the observations in the Gays Mills, Boscobel, and Wyalusing areas 1936–41; Chamberlin and Fluke, the observations in all other areas.

[2] The authors wish to express their appreciation to P. O. Ritcher who made the observations at Gays Mills in 1935 and to Lee Seaton who assisted continuously on all phases of the field work.

[3] For a more detailed consideration of the problem of sampling to determine host preferences of June beetles, see Insect Pest Survey Bul. 18, Sup. No. 4: 226–7, 1938.

main groves in addition to others nearby that were not listed as separate groves. With one exception, all the main groves were in the southern half of the State. Collections were not made from each grove every year, much depending on the areas in which beetles of the different broods emerged. Collections were made more intensively from the Gays Mills grove than from any other, therefore the results considered here are somewhat biased in favor of that area. As many as 17 collections were made in the main grove at Gays Mills in a single season, but the maximum per season in any other grove was 6. However, several groups of groves outside the Gays Mills area appeared to characterize the ecological complex of the particular localities, and the Gays Mills grove was the only one investigated that characterized that particular locality, therefore the bias is not considered material, except in regard to the host plant, cultivated cherry, which occurred chiefly at Gays Mills. In the 7-year period 261 separate collections were made in the main and subsidiary groves.

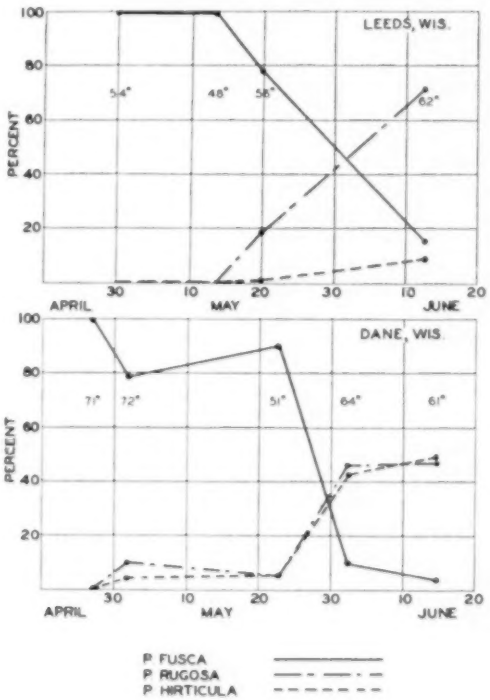

FIG. 1.—Proportional populations of various species of *Phyllophaga* on different dates and at different temperatures, 1938.

FLIGHT HABITS OF THE BEETLES.—Early in the season—that is, late in April or early in May—beetles usually began emergence about 7:30 P.M., standard time. As the length of the day increased, emergence began later, so that by mid-June it usually began about 8:20 P.M. Emergence was earlier on cloudy or darker evenings than on clear ones.

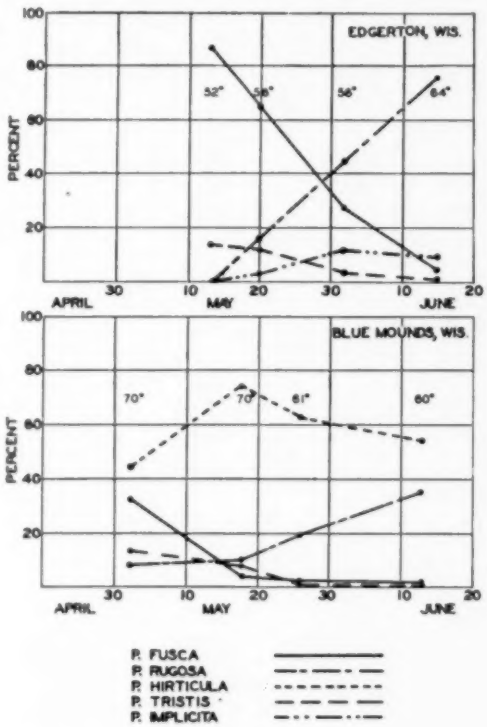

FIG. 2.—Proportional populations of various species of *Phyllophaga* on different dates and at different temperatures, 1938.

Emergence was influenced considerably by temperature. The air temperatures most favorable for emergence were 65° F. and above, although fair-sized emergences occurred at lower temperatures, especially if the soil temperatures were high. When emergence of beetles has been suppressed by cold and rainy weather, emergence is likely to take place at lower temperatures than usual. Under such conditions beetles emerged from the soil and, flying very little, crawled upon low shrubs and fed; consequently in some instances there was little evidence of flight, although fair

numbers had emerged and were feeding. Preferred conditions for emergence were warm evenings with slight wind and with little or no rainfall, although rather strong breezes and warm rains would not prevent emergence or feeding. In general, beetles rose from the soil against rather than with the air currents.

Some species emerged earlier in the season and at lower temperatures than

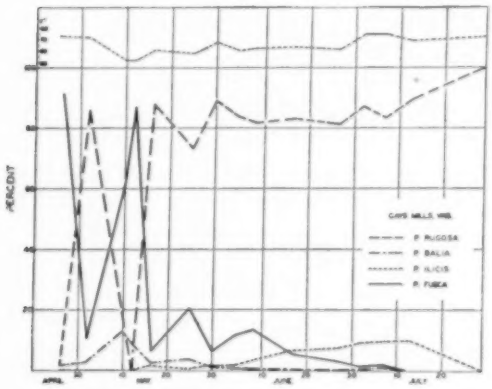

FIG. 3.—Proportional populations of various species of *Phyllophaga* on different dates and at different temperatures, 1938.

others. *Phyllophaga tristis* (F.) emerged and mated earlier and at lower temperatures than the common larger species. Of the larger species *P. fusca* (Froel.) emerged earlier in the season and at lower temperatures. Figures 1, 2, and 3 are based on observations made in 1938, but illustrate conditions usually observed. *P. tristis* was very scarce that year, and much significance cannot be given to records for that species. To avoid error in interpreting these figures, one should bear in mind that no indication is given in them of the actual number of beetles taken and that *P. fusca* predominated early in the season and *P. rugosa* (Melsh.) and *P. hirticula* (Knoch) later.

Figure 1 shows the temperature and seasonal relationships at the Leeds and Dane, Wis., groves. At Leeds, *Phyllophaga fusca* and *P. rugosa* predominate. In the first three collections, when temperatures were 56° F. or lower, *P. fusca* beetles were most abundant and in the first two collections no other species were taken. On June 13, when the temperature was 62°, *P. rugosa* predominated.

At Dane *Phyllophaga fusca*, *P. rugosa*, and *P. hirticula* were common. Early in the season, although temperatures were high, *P. fusca* predominated and the low temperature of May 23 increased the proportions. After this date temperatures remained high and this species remained in the minority. As shown in figure 1, the lines for *P. rugosa* and *P. hirticula* in this area are almost identical.

In figure 2 is given information from the Edgerton and Blue Mounds groves. At Edgerton *Phyllophaga fusca* and *P. rugosa* predominated. Of the four common species, *P. fusca* was most numerous on May 13 when the temperature was 54° F. and on May 20 when the temperature was 58°, but had declined by June 2, when the temperature was also 58°. Apparently 58° is high enough to induce a slow emergence of *P. rugosa* if the season is sufficiently advanced.

The Blue Mounds grove is at the north edge of an area in which *Phyllophaga hirticula* is most abundant. *P. hirticula* was predominant at Blue Mounds but *P. rugosa* and *P. fusca* were also fairly abundant. As shown by the figure, *P. hirticula* was most numerous in all the collections. *P. fusca* was more common than *P. rugosa* in the first collection but diminished in numbers afterward as *P. rugosa* increased.

The figure for the Gays Mills, Wis., grove (fig. 3) best shows the direct effect of temperature on emergence. Both *Phyllophaga fusca* and *P. rugosa* are common in this area. On April 26, with an air temperature of 73° F., over 90 per cent of the beetles were *P. fusca*, probably because no appreciable numbers of beetles of the other species had begun to emerge. By May 2, when the temperature was still high, *P. rugosa* had begun to emerge and most of the beetles were of that species. On May 10, however, when the temperature was 54°, about 60 per cent of the beetles were *P. fusca* and on May 12, when the temperature was also 54°, this species had increased to about 90 per cent of the total. When the temperature rose to 61° on May 16, the positions of the two species were again reversed. After this date temperatures remained high and *P. fusca* was always in the minority. This figure also shows that *P. ilicis* (Knoch) emerges late in the season and does not become abundant until considerably after its initial emergence. It should be pointed

out in this connection that, notwithstanding the changes in proportion of the various species in the emergences as the season advances, some of the species that emerge in greatest numbers early may persist in small numbers until very late in the season. This is particularly true of *P. fusca*.

SIZE AND IMPORTANCE OF FLIGHTS.—The flights of the brood A beetles, which emerged in the years 1935, 1938, and 1941, were larger than those of any other brood, and of these the 1935 flight was the largest. Flights of brood B have been the smallest, except that of 1936, when there was a large emergence of *Phyllophaga tristis*, a species with a 2-year cycle. That year there was a long period of drought in southern Wisconsin during the flight period and only extremely small numbers of grubs of this species were established in the field, notwithstanding the large numbers of beetles. *P. tristis* had been relatively scarce in southern Wisconsin since that time. The flights of brood C beetles have been strong in Lafayette and Iowa Counties and in the eastern part of Grant County. *P. hirticula* beetles comprise most of this brood but *P. fusca* beetles have been increasing in numbers recently. In Lafayette County this brood appears to be larger than brood A, although it consists largely of one species.

RELATIVE ABUNDANCE AND DISTRIBUTION OF SPECIES.—In the regular collections previously described, 56,344 beetles belonging to 18 species were collected. Included in this total also are 3 beetles that could not be positively identified but appeared to be hybrids. The number collected between 1935 and 1941, inclusive, the species, and the percentage of total comprised by each species, are shown in table 1.

The number given for *Phyllophaga tristis* in this list (table 1) is too small, because this species feeds extensively on the high parts of large oak trees, largely to the exclusion of other plants; and in 1936, when there was a tremendous flight of this species and extremely small flights of the others, their relative abundance could not be ascertained. The number was derived from collections from shrubs and the low branches of trees in groves where other species of beetles were present. The figure should be fairly accurate, however, if the year 1936 is not considered.

Grubs of the species *Phyllophaga rugosa*, *P. hirticula*, *P. fusca*, and *P. tristis* (before 1936) have been the most numerous in cereal and forage crops. Grubs of *P. implicita* have been rare in these crops. No grubs positively identified as *P. ilicis* have been dug in the field nor have adults of this species been reared from field-collected grubs. Grubs of a scarcer species, *P. futilis*, have been common in field crops in certain areas, especially in Lafayette County. Grubs of *P. inversa*, a species which had been rare in the areas studied, were very numerous along a weedy and grassy fence row near Lamont, Lafayette County, in 1941. Grubs of *P. prunina* have been encountered occasionally, especially in the sandy areas.

Table 1.—June beetles collected 1935–41 and the percentage of the total comprised by each species.

SPECIES	NUMBER	PER CENT	
Phyllophaga			
rugosa (Melsh.)	19,354	34.35	
hirticula (Knoch)	17,785	31.57	87.93
fusca (Froel.)	12,402	22.01	
implicita (Horn)	1,651	2.93	
tristis (F.)	1,185	2.10	
ilicis (Knoch)	1,097	1.95	
prunina (Lec.)	780	1.38	
drakei (Kirby)	576	1.02	
balia (Say)	490	.87	
futilis (Lec.)	393	.70	
nitida (Lec.)	320	.57	
crenulata (Froel.)	129	.23	
anxia (Lec.)	87	.15	
marginalis (Lec.)	58	.10	
spreta (Horn)	18	.03	
inversa (Horn)	11	.02	
forsteri (Burm.)	3	.005	
sp.? (hybrids?)	3	.005	
villifrons (Lec.)	2	.004	
	56,344	99.994	

As may be seen from table 1, *Phyllophaga rugosa*, *P. hirticula*, and *P. fusca* comprised almost 90 per cent of the total number of beetles taken. As to the species *P. spreta*, few specimens of which have been collected anywhere, nine males and nine females were collected at Gays Mills between 1935 and 1941, inclusive. P. O. Ritcher also collected one male and one female at the same place in 1934. This was the first time a female of *P. spreta* had been taken.

In table 2 are shown the localities in which each of the 18 species of beetles has been collected. Besides beetles col-

Table 2.—Distribution of species of Phyllophaga in Wisconsin.[1,2]

LOCALITY	*rugosa*	*hirticula*	*fusca*	*implicita*	*tristis*	*ilicis*	*prunina*	*drakei*	*balia*	*futilis*	*nitida*	*crenulata*	*anxia*	*marginalis*
1. Dane	x	x	x	x	x	x		x	x		x			x
2. Leeds	x	x	x	x	x	x		x		x	x			x
3. Blue Mounds	x	x	x	x	x			x		x	x		x	x
4. Edgerton	x	x	x	x	x	x	x	x	x	x	x	x	x	
5. Poynette	x	x	x	x	x		x	x				x		
6. Lodi	x	x	x		x	x	x	x	x			x		
7. Waunakee	x	x	x	x	x		x	x	x		x	x	x	
8. Linden	x	x	x	x	x	x	x	x		x	x		x	
9. Lamont	x	x	x	x	x	x		x	x	x	x	x	x	x
10. Hancock	x		x		x		x	x				x		
11. Ripon	x	x	x		x			x				x	x	x
12. Gays Mills	x	x	x	x	x	x	x	x	x		x		x	x
13. Madison	x	x	x	x	x		x	x			x			
14. Verona	x	x	x	x	x									
15. Blanchardville	x	x	x											
16. Hollandale	x	x	x	x		x		x			x	x		x
17. Whitewater	x		x											
18. Racine	x		x		x			x		x			x	
19. Merrimac	x		x	x						x				
20. Oregon			x											
21. Boscobel	x	x	x	x	x		x							
22. Mineral Point		x	x		x									
23. Wyalusing	x		x	x	x				x					
24. Black Earth				x	x				x			x		x
25. Wisconsin Rapids					x			x				x		
26. Beaver Dam	x		x					x						
27. Fairwater	x		x											
28. Sturgeon Bay	x		x										x	
29. Milton	x	x	x	x				x	x	x				
30. Black River Falls			x											
31. Eau Claire					x									
32. La Valle					x									
33. Durand					x									
34. Arcadia					x									
35. Fountain City				x										
36. Beetown	x			x						x				
37. Orfordville				x										
38. Viroqua				x										
39. Baldwin				x										

[1] This table should be used in conjunction with the map of Wisconsin (fig. 4). The localities on the map have the numbers of the same localities in the table.

[2] Also *P. spreta*, Gays Mills; *P. inversa*, Blue Mounds, Lamont, Gays Mills, Merrimac and Black Earth; *P. forsteri*, Leeds, Gays Mills; *P. villifrons*, Lamont, Gays Mills and Madison.

lected in the type groves, this table includes beetles collected incidentally, some sent in, and others dug from the field. This table should be used in conjunction with the map of Wisconsin in figure 4. On the map the localities are represented by numbers which are the same as those preceding the localities in table 2. Generally speaking, the most extensive collections were made in localities 1 to 14, inclusive, and localities 30 to 39, inclusive, are those from which we have only single records. In all but one of these latter localities only a single species is recorded, but doubtless the more abundant and more widely distributed species also occur there.

HOST PREFERENCES OF THE BEETLES.—According to our listing, June beetles were taken from 69 kinds of plants, of which the identity of 4 was uncertain. However, some groups of related plants such as oaks of the red oak group, *Crataegus* spp., etc., were considered as single species, therefore the actual number of species of host plants was over 70—probably 75 or more. This loose classification was obligatory because some of the groups are imperfectly understood, even by taxonomists, and because of the difficulty in determining plants at night, especially before they have leafed out fully.

The chief host plants of June beetles in general are shown in table 3 and the chief host plants of the principal species in table 4. An examination of these tables shows definitely the importance of hazel brush, bur oak, and hickory as food for the beetles and also shows that if destruction of any considerable number of the June beetles in any locality is attempted, the shrub hazel must be treated with poison, in addition to the trees. As can be concluded from data in table 4, the particular trees or shrubs to be treated in any area should be selected on the basis of the predominant species of June beetles in that area. From this table it appears also that control of adults and indirectly of their grubs by spraying or dusting would be very difficult when *Phyllophaga rugosa*, *P. fusca*, and *P. futilis* were the

Table 3.—Chief host plants of June beetles in southern Wisconsin, 1935–41.

HOST PLANT	BEETLES COLLECTED	
	Number	Percentage of Total
Hazel	12,173	21.60
Bur oak	8,105	14.38
Hickory	5,247	9.31
Cherry (cultivated)	4,731	8.40
Populus spp., mostly aspen	4,677	8.30
Red oak group	4,122	7.32
Butternut	3,971	7.05
Dogwood	3,252	5.77
Willow	2,186	3.88
White oak	1,344	2.37
	49,798	88.38

predominating species, since these have 10, 8, and 12 principal hosts, respectively. Control should be less difficult when *P. hirticula*, *P. tristis*, *P. implicita*, and *P. ilicis* are concerned, because these species tend to concentrate their feeding on few kinds of plants.

In considering the data in the foregoing tables, it should be borne in mind that, while these show clearly the kinds of plants preferred by various species of

FIG. 4.—Map of Wisconsin showing the localities in which June beetles were collected, 1935–41. The numbers on the map are the same as those of the localities named in table 2.

Table 4.—Chief hosts of principal species of Phyllophaga collected in 1935–41, with percentage of each species collected from plants named.

HOST PLANT	*P. rugosa* PER CENT	*P. hirticula* PER CENT	*P. fusca* PER CENT	*P. implicita*[1] PER CENT	*P. tristis* PER CENT	*P. ilicis* PER CENT	*P. futilis*[1] PER CENT
Cherry (cult.)	18.20	—	8.60	—	—	2.83	—
Hickory	12.78	7.29	9.16	—	—	12.67	—
Butternut	10.52	—	11.61	—	—	20.15	—
Hazel	9.97	45.41	6.90	—	—	42.11	34.86
Populus spp., mostly aspen	9.73	—	11.35	44.94	—	—	—
Willow	5.93	—	—	47.73	—	—	—
Red oak group	5.67	4.11	9.63	—	23.04	—	—
Bur oak	4.68	28.66	10.65	—	60.34	—	2.29
Basswood	3.65	—	—	—	—	—	2.80
Elm	3.29	—	—	—	—	—	8.14
Dogwood	—	—	18.89	—	—	—	5.09
White oak	—	—	—	—	4.47	—	—
Ironwood	—	—	—	—	—	3.46	—
Prickly ash	—	—	—	—	—	—	10.69[2]
Plum (cult.)	—	—	—	—	—	—	5.09
Rose (wild)	—	—	—	—	—	—	4.58
Raspberry	—	—	—	—	—	—	4.09
Plum (wild)	—	—	—	—	—	—	3.31
Gooseberry	—	—	—	—	—	—	2.29
Locust	—	—	—	—	—	—	2.29
Total Per Cent	84.42	85.47	86.79	92.67	87.85	81.22	85.52
Total Number	16,326	15,202	10,768	1,530	1,041	891	336

[1] Records of other workers and those of the authors for the year 1942 show elm to be an important host plant of this species.
[2] In the Blue Mounds grove, where both hazel and prickly ash (*Xanthoxylum americanum*) are abundant, prickly ash appears to be the preferred host.

June beetles for food, they are not an entirely accurate measure of the importance of the various plants as hosts in all localities. For example, in large areas where *Phyllophaga hirticula* is numerous, the host plant bur oak is more abundant than hazel, and individual bur oak plants furnish more foliage to be fed on than do individual hazel plants. In regard to cultivated cherry, which supplied many of the *P. rugosa* and *P. fusca* beetles, this plant can be important only in those limited areas in which it is grown commercially.[1]

The chief deciduous trees rarely fed on by any of the species collected in Wisconsin are maples and boxelder. In the 7-year period only 5 beetles were collected from maple, whereas 162 were taken from boxelder, 138 of them being *Phyllophaga rugosa*. Most of these were taken at the Gays Mills grove. On many nights when beetles were abundant in groves examined, practically no feeding on boxelder occurred.

Among the herbs and shrubs on which June beetles rarely have been found feeding are quackgrass, red clover, alsike clover, sweet-clover, sumac, bittersweet, lead plant (*Amorpha canescens* (Pursh)), poison ivy, *Geum* sp., elderberry, blueberry, milkweed, mullein, bull thistle, and timothy.

[1] For a more detailed consideration of the host preferences, refer to Insect Pest Survey Bul. 18, Sup. No. 4; 19, Sup. No. 3; 20 Sup. No. 9; and 22, Sup. No 3

SUMMARY.—In the period 1935 to 1941, inclusive, 56,344 June beetles were collected from host plants in groves in Wisconsin. With one exception these groves were in the southern part of the State. Eighteen species were taken, of which the predominant ones were *Phyllophaga rugosa*, *P. hirticula*, *P. fusca*, *P. implicita*, *P. tristis*, and *P. ilicis*. The first 3 species comprised 87.93 per cent of the total taken. Grubs of *P. rugosa*, *P. hirticula*, *P. fusca*, and *P. futilis* were most common in field crops.

Although influenced by soil temperatures and other factors, emergence of the beetles from the soil was highest when the temperature was 65° F. or above. Early in the season emergence began about 7:30 P.M. but toward the end of the season, as the daylight period lengthened, about 8:20 P.M. Emergence was earlier on cloudy evenings than on those not cloudy.

The predominant species were taken from host plants as follows: *Phyllophaga rugosa*, 84 per cent from 10 kinds; *P. fusca*, 87 per cent from 8 kinds; *P. futilis*, 85 per cent from 12 kinds; *P. hirticula*, 85 per cent from 4 kinds; *P. implicita*, 93 per cent from 2 kinds; *P. ilicis*, 81 per cent from 4 kinds; and *P. tristis*, 88 per cent from 3 kinds.

Control of the first three species in this list by spraying or dusting of host plants would be more difficult than that of the four last-named species.—5-19-43.

R. R. HEATON

Captain R. R. Heaton is said to be in North Africa, his address being APO 4773, c/o Postmaster, New York City. Captain Heaton has received his promotion since our last mention of him in the *Journal*.

PHILIP LUGINBILL, JR.

Ensign Philip Luginbill, Jr., Navy. Rec. Station, Tacoma, Washington, is awaiting assignment to a ship, presumably for duty in the Southwest Pacific.

ROBERT V. NARDY

Sergeant Robert V. Nardy is now in foreign service. His address is 10th E. F. F. D., APO 505, c/o Postmaster, New York City. Mr. Nardy formerly assisted Dr. Donald L. Collins in Dutch Elm Disease and Japanese Beetle Studies at Yonkers, New York.

LIEUTENANT D. W. LAHUE

Delmon W. LaHue is now a First Lieutenant and is stationed at the Port Surgeon's Office, Newport News, Virginia. His work includes the testing of the value of methyl bromide in disinfestation work.

LIEUTENANT W. D. MILLER

W. D. Miller, formerly of Purdue, has received a commission as an Entomologist with the rank of Second Lieutenant. He is now assigned to a special training course at Carlisle Barracks, Pa.

WM. M. MACHADO

Sergeant Wm. M. Machado, formerly an associate of Dr. Donald L. Collins, at Geneva, New York, is now with the 42d Malaria Control Unit, New Orleans Staging Area, New Orleans, Louisiana.

Oviposition of June Beetles and the Survival of Their Offspring in Grasses and Legumes

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The use of legumes in crop rotation or as substitutes for other crops has long been recommended as a means of reducing grub populations and damage. Among the more recent publications are those of Fluke *et al.* (1932), Graber & Fluke (1934), Graber (1936), Burcalow & Bohstedt (1940) and Burcalow & Ahlgren (1942), which deal chiefly with pasture renovation by the use of sweetclover. However, the preference of grubs for grass over other crops, especially legumes, was observed earlier. C. H. Baldwin (1912) wrote that grubs tended to be numerous in grass, and land that has been in grass should be planted to some other crop before strawberries are planted on it. Menges (1913) wrote as follows:

> Pennsylvania farmers have . . . been following a system of crop rotation which in most instances has not given the insect enemies of individual crops sufficient time to pass through all stages of development until their food supply was removed and another crop put into its place. When damage from insects came to crops in this state they were enemies of crops removed or they transferred their depredations to crops in rotation.
>
> Whenever possible the grasses, such as corn, should follow clover, because the enemies of clover are so different. . . . Some farmers think they are plowing down a clover sod for corn after they have had a field in grass for two or three years, but usually it is a grass sod field full of larvae that can feed on corn as well as grass.
>
> The white grubs are among these larvae . . . [white grubs] do not thrive in clover sods, and, by instinct, the female does not lay her eggs in the clover field but rather in timothy fields.

Parks (1918) wrote: "Land properly rotated rarely becomes infested with either of these underground insects [white grubs and wireworms]. They do not attack legume crops, and consequently a rotation which provides for a legume, such as red clover, for 1 year in 3 or 1 year in 4 will usually protect cereal crops from attack."

The work of entomologists previously has shown that grubs tend to be less numerous in legumes than in grasses, but no one seems to have understood clearly the reasons for this distribution. The explanation most commonly encountered was that legumes were repellent to the adult beetles, consequently the beetles did not lay eggs in them.

Field diggings over several years in southern Wisconsin substantiated the results of earlier workers in showing that grubs were commonly more numerous in grass than in legumes. Soon after initiation of the current investigations in 1935, however, a number of heavy grub populations were found in both sweetclover and alfalfa fields, and it was known that the eggs producing the grubs had been laid in those crops. In a few legume fields the populations exceeded those in adjoining bluegrass. Apparently, therefore, legumes as such were not actually repellent to the beetles. It appeared likely that variation in the extent of oviposition was determined by different soil conditions produced by the different crops under varying climatic conditions. Furthermore, since bluegrass produces a close mat of roots and rhizomes and the deep-rooted legumes do not, the food supply in grass is more abundant and more easily available, especially for young grubs. It seemed reasonable, therefore, that the tendency for grubs to be more numerous in grass than in legumes could be partly attributed to failure of grubs to survive well in legumes.

The experiments described herein were conducted to determine whether beetles would lay eggs as freely in legumes as in bluegrass and whether the grub-survival

[1] With the Department of Entomology, University of Idaho, since August 31, 1942.

[2] The authors are much indebted to C. L. Fluke of the Department of Economic Entomology, University of Wisconsin, for advice and criticism and for the use of many unpublished records of that Department and to Lee Seaton, who assisted in all phases of the field work.

rates in these crops were different. As existing information indicated that bluegrass was among the crops most favorable and sweetclover among those least favorable for oviposition of beetles and survival of grubs, the crops first compared were bluegrass and sweetclover. In 1942 alfalfa was also tested.

FIG. 1.—Oviposition cages without tops at Lamont, Wis., 1940. The two rows of cages at the right contain sweetclover; those at the left bluegrass.

EXPERIMENTAL SET-UP.—Tests were made in unit cages set in equal numbers in each crop, each cage inclosing about 4 square feet. The bases of the cages were made of galvanized sheet iron forming a square with the sides slightly over 25 inches long and 8 inches high. The top half-inch of the bases was bent outward and downward at an angle of 45° to form a flange. These flanges served to strengthen the bases and as a means of attaching the cage tops securely. The bases were set into the soil to a depth of 4 inches. In the earlier tests the tops were of muslin or surgical gauze, the edges of which were fastened beneath the flanges with string or rubber bands encircling the bases. Ventilation in the cages was poor when cloth tops were used, and later the tops were made of squares of 14-mesh screen, the edges being bent securely around and under the flanges. The cloth tops were elevated in the middle by stakes driven into the soil. On top of each stake was tacked the lid of a 2-ounce salve box. The screen tops were flat.

The cages were set and covered before the flight of the beetles had begun or while the flights were still small. When flights had become heavy and it was estimated that egg laying was about to begin, equal numbers of females, and where possible the same numbers of males, were placed in each cage. The number of males was considered unimportant because probably the females had already mated.

In most of the tests the sweetclover and alfalfa were seeded in the spring of the year in which the tests were begun, and if the stand thinned out there was some reseeding. The bluegrass was natural growth unseeded. The cages were weeded frequently to keep the crops as clean as possible. Diggings of cages usually were made in lots of two or three and the counts were considered the population for the particular time of the year. Rains or other circumstance sometimes prevented all cages of each sample from being dug during the same few days. In such cases the cages were dug at as nearly the same time as possible.

The initial populations, in the form of eggs and first instars, were determined by diggings made in August of the first year. Doubtless there had been some mortality by this time but, because of the prolonged egg laying and hatching period, there appeared to be no time when an initial population could be determined exactly. A fall digging was made late in September or in October. In the first experiments which dealt with grubs of the 1940 brood, diggings were also made in June, September, and October of the second year, and in June and July of the third year.

FIG. 2.—Oviposition cages with muslin tops at Lamont, Wis., 1940.

It was found that the heaviest mortality occurred the first year, sometimes being so great as practically to eliminate the grubs in the legume cages; consequently, second- or third-year diggings were not made in all cages.

One or more experiments were begun each year at Lamont and at Gays Mills,

both in Wisconsin. In 1940 and 1941 *Phyllophaga hirticula* (Knoch) was used at Lamont and *P. rugosa* (Melsh.) at Gays Mills. These species have been most abundant in field crops since the beginning of investigations in 1935. In 1942 it was necessary to use *P. implicita* (Horn) in most of the cages but, with one exception, infestations in the cages by this species were so low that the study was discontinued. The experiments dealing with this species, therefore, are not considered in this paper.

and the known variation in the number of eggs laid by female beetles. An unusually low or high population in a single cage in some cases changed the average for the sample considerably. Furthermore, it became apparent that uniform stands could not be maintained in all cages nor could the cages be kept equally free from weeds. It was especially difficult to keep the cages free from white Dutch clover, which is a sod-forming legume, and field diggings have indicated that white grubs thrive in it. Thus while its presence in the bluegrass probably would not affect the results materially, its presence in sweetclover, if the latter were an unfavorable crop, could affect the results.

Table 1.—Oviposition of beetles and survival of grubs of the 1940 brood of *Phyllophaga hirticula* in bluegrass and sweetclover at Lamont, Wis.

Date Examined	Sod							Sweetclover						
			Instar							Instar				
	Cage No.	Eggs	1st	2d	3d	Total	Avg.	Cage No.	Eggs	1st	2d	3d	Total	Avg.
1940														
Aug. 8	(1)	71	88	0	0	159	155	(1)	58	31	0	0	89	$77\frac{1}{2}$
Aug. 15	(2)	17	206	3	0	226		(2)	5	22	0	0	27	
Aug. 23								(3)	14	112	0	0	126	
Aug. 30	(3)	17	61	2	0	80								
Sept. 26	(4)	0	26	126	0	152	134	(4)	0	37	4	0	41	$25\frac{1}{2}$
Oct. 3	(5)	0	90	26	0	116		(5)	0	7	3	0	10	
1941														
May 21	(6)	0	11	12	0	23	13	(6)	0	1	0	0	1	15
May 21	(7)	0	3	0	0	3		(7)	0	21	8	0[1]	29	
June 25	(8)	0	0	37	33	70	$36\frac{1}{2}$	(8)	0	1	12	1	14	$10\frac{1}{2}$
June 25	(9)	0	3	0	0	3		(9)	0	0	7	0	7	
Sept. 17	(10)	0	0	0	4	4	16	(10)	0	0	0	0	0	$\frac{1}{2}$
Sept. 17	(11)	0	0	0	28	28		(11)	0	0	0	1	1	
1942														
June 15	(12)	0	0	0	21	21	12	(12)	0	0	0	0	0	0
June 15	(13)	0	0	0	3	3		(13)	0	0	0	0	0	

[1] This cage had been invaded to a considerable extent by white Dutch clover.

EXPERIMENTAL RESULTS.—The individual experiments will be considered first. The results obtained from the experiment with the 1940 brood of *Phyllophaga hirticula* at Lamont are given in table 1. Each cage contained 15 males and 15 females.

Before studying this table and those which follow, certain facts should be considered. The counts did not always show a decrease in population with the increase of time, which obviously they should have shown in the true course of events. These irregularities were expected, however, because of the small number of cages used

Another complicating factor was the invasion of cages by carabid beetle larvae and adults. The carabids destroy many eggs and grubs (Seaton 1939) and their concentration, which was evident in some of the cages, is believed to have affected the results.

It may be noted in table 1 that the average population per cage in the initial diggings was almost exactly twice as high in the bluegrass as in the sweetclover. In

the spring of 1942 there was an average population in the bluegrass of 12 grubs per cage and none in the sweetclover. Based on the initial and final populations, the reduction in population between August 1940 and June 1942 in the bluegrass was approximately 13 to 1 and there was no survival in the sweetclover.

It may be observed that at the time of the initial digging second-instar grubs were beginning to appear in the bluegrass cages but not in the sweetclover cages, and that in the fall digging second instars for some unknown reason had not obtained sufficient food, a condition which probably would increase the mortality rate. On the other hand, the population in one of the sweetclover cages was higher than would be expected on the basis of the previous sweetclover counts and their relation to the corresponding bluegrass counts. As indicated in table 1, this sweetclover cage had been invaded by white Dutch clover, which probably aided the grubs to survive. This population was in line with the previous ones, however, to

Table 2.—Oviposition of beetles and survival of grubs of the 1940 brood of *Phyllophaga rugosa* in bluegrass and sweetclover at Gays Mills, Wis.

Date Examined	Sod							Sweetclover						
			Instar							Instar				
	Cage No.	Eggs	1st	2d	3d	Total	Avg.	Cage No.	Eggs	1st	2d	3d	Total	Avg.
1940														
Aug. 23	(1)	0	70	1	0	71		(1)	37	101	0	0	138	
Aug. 23	(2)	1	88	4	0	93	$74\frac{2}{3}$	(2)	8	105	0	0	113	$117\frac{1}{3}$
Aug. 23	(3)	0	57	3	0	60		(3)	2	99	0	0	101	
Sept. 12	(4)	0	1	20	0	21		(4)	0	30	1	0	31	
Sept. 19	(5)	0	16	72	0	88	58	(5)	0	16	0	0	16	$18\frac{1}{3}$
Sept. 19	(6)	0	26	39	0	65		(6)	0	8	0	0	8	
1941														
June 5	(7)	0	7	57	0	64		(7)	0	1	0	0	1	
June 5	(8)	0	14	43	0	57	62	(8)	0	0	0	0	0	
June 5	(9)	0	15	50	0	65		(9)	0	1	0	0	1	
Aug. 6	(10)	0	4	7	39	50								
Aug. 6	(11)	0	4	4	56	64	$53\frac{2}{3}$	Digging of these cages abandoned because of low populations.						
Aug. 6	(12)	0	0	6	41	47								
Oct. 29	(13)	0	6	32	26	64	64							

were very numerous in bluegrass but scarce in sweetclover. First instars predominated in sweetclover until June 1941 and only two grubs developed to the third instar throughout the whole period, notwithstanding a high initial population.

The reductions in population in both crops appeared to be continuous, except for the results of the May 1941 digging. These results appear to be out of line for several reasons. The average population of the bluegrass cages was lower than was to be expected from the populations shown by the diggings immediately preceding and following, and there was an abnormally high percentage of first instars in both cages, a condition not observed in bluegrass before. This indicated a delayed development, suggesting that the grubs the extent that most of the grubs were in the first stadium.

In table 2 are given the results with the 1940 brood of *Phyllophaga rugosa* at Gays Mills. Each cage contained 4 males and 7 females. In this experiment the initial population in the bluegrass cages was slightly less than two-thirds of that in the sweetclover cages, but on the last date on which diggings were made in both crops, June 5, 1941, there were almost 100 times as many grubs in the bluegrass as in the sweetclover. The reduction in population between August 23, 1940, and June 5, 1941, was approximately in the proportions of 1.2 to 1 in the bluegrass and 176 to 1 in the sweetclover.

In this test, as in that at Lamont, second instars were present in the initial

digging in the bluegrass but not in the sweetclover. In the fall digging there were 131 second instars in the 3 cages of bluegrass and only 1 in the 3 cages of sweetclover. In the spring digging in 1941 there were 150 second instars in the 3 cages in bluegrass and none in the sweetclover.

Table 3 gives the results with the 1941 brood of *Phyllophaga hirticula* at Lamont, Wis. This test was conducted for 1 year. In each cage were placed 15 males and 15 females.

The initial populations obtained were much lower than those of 1940. Here, as in the 1940 experiment with this species, that in cages in which the initial populations were low the final counts may not be very significant, because of invasion by extraneous grubs.

Early in the work it was thought that no grubs or only a few would enter the cages from outside and that, even if they did, the records would give a fair estimate of relative grub mortalities in the different crops. At first no attempt was made to determine the species of grubs collected in the cages because of the high mortality between the time the grubs were collected and the time when it was possible to determine them in the laboratory. Later,

Table 3.—Oviposition of beetles and survival of grubs of the 1941 brood of *Phyllophaga hirticula* in bluegrass and sweetclover at Lamont, Wis.

Date Examined	Bluegrass							Sweetclover						
			Instar							Instar				
	Cage No.	Eggs	1st	2d	3d	Total	Avg.	Cage No.	Eggs	1st	2d	3d	Total	Avg.
1941														
Aug. 21	(1)	0	55	0	0	55	62.5	(1)	0	33	0	0	33	22½
Aug. 22	(2)	1	67	2	0	70		(2)	0	12	0	0	12	
Sept. 18	(3)	0	3	23	0	26	26	(3)	0	0	0	0	0	0
1942														
June 10	(4)	0	0	10	0	10	11	(4)	0	5	0	0	5	3½
June 10	(5)	0	0	12	0	12		(5)	0	0	2	0	2	

the initial population in bluegrass was higher than in the sweetclover, in this case almost three times as high. In the fall of the first year 26 grubs (3 in the first stadium and 23 in the second) were found in the single bluegrass cage that was dug and none in the sweetclover cage. In June of the next year, 1942, there were almost 3 times as many grubs in the bluegrass as in the sweetclover. All the 22 grubs from bluegrass were in the second stadium, while only 2 of the 7 in sweetclover were in that stadium, which again indicated delayed development in the sweetclover. The reduction in population between August 1941 and June 1942, as indicated by the final counts, was about 6 to 1 in both the bluegrass and the sweetclover. Considering the results of the two experiments with grubs of the 1940 brood previously described, and the fall populations in the cages in this particular experiment, the final results were the reverse of what was expected. However, in connection with this experiment it became apparent when the number of surviving grubs became reduced and most of them were in the third stadium and consequently relatively easy to determine, it was found that occasionally a fairly high percentage of grubs belonged to species other than that colonized. It was clear, therefore, either that larvae originally outside the cages had entered them or that adults of other species were in the soil at the time the cages were set. Use of deeply sunk cages, such as tiles, would have eliminated grub migration but previous studies had shown these to be unsatisfactory in other respects. It was learned later that a few beetles of other species had been present in some of the cages but, as no traces of intermediate stages of grubs were found in cages previously dug, it was thought more likely that the third instars had entered the cages by migration and had not been produced by adults in the cages. Thus the fact that first instars decreased greatly in numbers in the sweetclover the first year without entering the second

Table 4.—Oviposition of beetles and survival of grubs of the 1941 brood of *Phyllophaga rugosa* in bluegrass and sweetclover at Gays Mills, Wis.

Date Examined	Bluegrass							Sweetclover						
	Cage No.	Eggs	Instar 1st	Instar 2d	Instar 3d	Total	Avg.	Cage No.	Eggs	Instar 1st	Instar 2d	Instar 3d	Total	Avg.
1941														
Aug. 8	(1)	6	26	0	0	32		(1)	0	11	0	0	11	
Aug. 8	(2)	1	33	0	0	34	28⅓	(2)	0	0	0	0	0	3⅔
Aug. 8	(3)	0	19	0	0	19		(3)	0	0	0	0	0	
Oct. 29	(4)	0	7	14	0	21		(4)	0	1	0	0	1	
Oct. 29	(5)	0	8	7	0	15	17⅔	(5)	0	3	5	0	8	5
Oct. 29	(6)	0	7	10	0	17		(6)	0	3	3	0	6	
1942														
July 9	(7)	0	2	3	0	5		(7)	0	0	0	1	1	
July 9	(8)	0	3	31	11	45	19⅔	(8)	0	0	1	0	1	⅔
July 9	(9)	0	4	4	1	9		(9)	0	0	0	0	0	

stadium in appreciable numbers is regarded as more significant than the final counts. There is, of course, no way of ascertaining whether the emigration of grubs was not equal to the immigration, but in the cages in which the final population was relatively high and in which there were few or no grubs in the cages dug just previously, it seems reasonable to conclude that the migration had been largely inward.

In table 4 are shown the results of the experiment with the 1941 brood of *Phyllophaga rugosa* at Gays Mills. In each cage 4 males and 8 females were placed. Here also the initial population was much lower than in 1940. The initial population was almost 8 times as high in the bluegrass as in sweetclover. The late fall population was over 3 times as great and the spring population of 1941 almost 30 times as great in the bluegrass as in the sweetclover. The results of this experiment differed from those previously discussed in that, comparatively speaking, a large number of second instars were produced the first year in the sweetclover. The presence of these second instars may have been the result of weed intrusions. The indicated survival of grubs was fairly high in both crops but much higher in the bluegrass.

The results of the experiment at Lamont with 1942-brood *Phyllophaga hirticula* are given in table 5, five males and seven females having been placed in each cage. This experiment is not complete, some cages remaining to be dug in the spring of 1943, but it is believed that the most important data have already been obtained.

With respect to establishment and survival of grubs in bluegrass, the results of this experiment with the 1942 brood

Table 5.—Oviposition of beetles and survival of grubs of the 1942 brood of *Phyllophaga hirticula* in bluegrass, sweetclover, and alfalfa at Lamont, Wis.

Date Examined	Bluegrass					Sweetclover					Alfalfa				
	Cage No.	Instar 1st	Instar 2d	Total	Avg.	Cage No.	Instar 1st	Instar 2d	Total	Avg.	Cage No.	Instar 1st	Instar 2d	Total	Avg.
1942															
Aug. 26	(1)	23	35	58	37	(1)	0	0	0	1.5	(1)	12	0	12	6.5
Aug. 26	(2)	12	4	16		(2)	2	1	3		(2)	0	1	1	
Sept. 30	(3)	0	61	61	60	(3)	3	4	7	4	(3)	0	0	0	.5
Sept. 30	(4)	5	54	59		(4)	0	1	1		(4)	0	1	1	

agreed essentially with those dealing with the 1940 brood at both Lamont and Gays Mills. They differed in that establishment in sweetclover was relatively poor. They differed from the tests of the 1941 brood in that establishment of grubs in the bluegrass was much better. Why the grubs were so scarce in the sweetclover and alfalfa in the initial diggings is not known. However, the growth of the sweetclover was very poor during the confinement of the beetles when the cages were covered, and there was considerable bare ground in some of the cages at the time of digging. It is possible, therefore, that there was some grub mortality before the initial diggings made on August 26, or it may have been that the beetles refused to lay eggs where there was so little vegetative cover.

It should be pointed out that the determination of many grubs dug in this 1942 experiment, as well as in those dealing with *Phyllophaga implicita*, mentioned previously but not otherwise reported in this paper, showed that they belonged to the species colonized in the particular cages. It appears, therefore, that complications arising from larval intrusions are likely to be encountered chiefly when dealing with second- or third-year grubs.

DISCUSSION.—In two experiments dealing with the 1940 brood of beetles and their offspring (Tables 1 and 2), oviposition by the beetles and the initial establishment of the grubs in cages was high in both bluegrass and sweetclover. In one experiment, in which *Phyllophaga rugosa* was used, establishment was 1.5 times as high in the sweetclover as in the bluegrass. In the other where *P. hirticula* was used, establishment was twice as high in the bluegrass as in the sweetclover. In a third experiment with the 1942 brood of *P. hirticula* (Table 5), oviposition and establishment of the grubs was excellent in the bluegrass but poor in sweetclover and alfalfa. These three experiments indicate that at times beetles may oviposit in sweetclover just as heavily as or more heavily than in bluegrass, provided the beetles are confined with the plants, but the importance of this qualification is diminished in the light of field observations and supplementary cage experiments, which showed that oviposition may be just as heavy in sweetclover as in bluegrass when the beetles are able to make a choice.

In any of these experiments where the initial population was high enough so that the final count could be regarded as significant, only a very small part of the grubs hatching from eggs laid in sweetclover lived to attain the second instar. In other words, mortality is much heavier in sweetclover than in bluegrass, especially during the first year. This is strong evidence to show that, generally speaking, low populations in sweetclover in the field are caused by failure of grubs to develop properly in sweetclover the first year. Diggings showed that in dry or moderately dry weather the soil in the sweetclover cages was drier on top and dry to greater depths than that in the bluegrass cages and that only in periods of more or less continuous rain did the soil in the sweetclover cages remain moist to any considerable depth. Unless the sweetclover cages had been invaded by grass, there was no compact mat of fine roots, such as characterized the bluegrass cages. These differences in soil conditions and root growth appear to have been sufficient to produce the considerable difference in grub survival shown by the samples.

The first two of the three experiments just discussed are regarded as the most significant of all those conducted, because in these the oviposition and establishment of the grubs was high in both the sweetclover and the bluegrass and, with high initial populations, relative mortalities could be measured more accurately and digging could be continued with profit through the second or into the third year. In the remaining two experiments (Tables 3 and 4) in which the 1941 brood of beetles was used, oviposition by the beetles and establishment of the grubs were not so good as in the 1940 experiments. No cause for this difference could be ascertained but establishment of grubs of the 1941 brood was very poor in the field at large, notwithstanding a large beetle flight. Establishment of grubs in these experiments was higher in the bluegrass than in the sweetclover. Because of the low initial populations, the later figures are probably not very significant as measures of the previous mortality, since their value could have been changed materially by entrance of a few extraneous grubs into the cages. The failure of grubs in sweetclover to attain second instars in sweet-

clover in appreciable numbers, however, was shown by the data in tables 3 and 4.

CONCLUSIONS.—The fact that grub populations are usually lower in deep-rooted legumes, such as sweetclover and alfalfa, than in grass appears to be the result of two main factors—usually fewer eggs are laid, and mortality of grubs is higher in such legumes than in grass. Thus a lower initial population is to be expected in clean stands of legumes; and if, as sometimes happens, the initial population is high, it may be expected to be reduced to inconsequential numbers by the time grubs are ready to hibernate the first year. Legumes as such are not actually repellent to June beetles, therefore the usual preference of the beetles for grass rather than deep-rooted legumes is probably the result of different soil conditions produced by the two types of crops. Failure of grubs to survive in the legumes the first year appears to be because there is no compact mat of fine roots and rhizomes on which the young larvae can feed easily and also because of difficulty in burrowing through hard, dry soil—a condition of more frequent occurrence in legumes than in grass—to reach their food supply. Once established, a moderate number of second or third instars probably can live very well in legumes, especially if the crop is not clean. It is known that roots of alfalfa and sweetclover are acceptable to second or third instars, because new plantings of these crops on land already heavily infested with second-year grubs are sometimes severely injured or destroyed by them.

These experiments have shown that the use of deep-rooted legumes, either as more or as less permanent crops of hay or pasture or in rotation, is of great value in keeping grub populations at a minimum. In rotations, prevention of damage by grubs would be more effective if as much land as possible were in deep-rooted legumes in the years when major flights of beetles occur.—5-24-43.

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JOHN C. DEAL, JR.

Mr. Deal, now a First Lieutenant, reports that he is stationed "on a rock" in the South Pacific. He may be addressed c/o Fleet Post Office, San Francisco, California. Lieutenant Deal is attached to the Marines.

W. E. MCCAULEY

Captain W. E. McCauley, formerly a contributor to the *Journal* from Illinois, has recently received his promotion. He is located in the Southwest Pacific and may be addressed through APO 301, c/o Postmaster, San Francisco. He reports insects in great abundance, particularly the more noxious or obnoxious sorts.

HERBERT E. MILLIRON

Herbert E. Milliron, an Entomologist in the Army with the rank of First Lieutenant, has been transferred to Camp Atterbury. Lt. Milliron owes entomological allegiance to West Virginia, Michigan State and Minnesota.

JAMES A. CLARK

Sergeant James A. Clark is reported to be in Australia where he was sent to recuperate from wounds received in New Guinea. Sergeant Clark is a Purdue graduate.

BRUCE M. HENIFORD

B. M. Heniford has been promoted to First Lieutenant and may be addressed APO 34, c/o Postmaster, New York. He has been in North Africa since June. He is learning more about the part that insects play in causing disease by first-hand observation.

ENSIGN R. B. EADS

Richard B. Eads, formerly with the Texas State Board of Health at Austin is now at the Naval Medical School, Bethesda, Maryland. He may be addressed as follows: Ensign Richard B. Eads, H-V(S), U.S.N.R. Naval Medical School, Bethesda.

The Ecology and Control of Wireworms in the Connecticut River Valley[1]

WALTER M. KULASH,[2] *North Carolina State College, Raleigh*

The methods recommended by the earlier workers for the control of wireworms such as means for making seed resistant to attack and cultural practices were not always based on an adequate knowledge of the habits of various species of wireworms. Later investigations have shown that seed treatment and fall and spring plowing are not effective means of controlling wireworms. Seed treatment with certain chemicals may not be a sure means of repelling the larvae even though the chemical used may be distasteful and poisonous to the larvae. Woodworth (1938) has shown that larvae of the Pacific Coast wireworm, *Limonius canus* Lec., are capable of rejecting arsenicals even after burrowing into baits containing these poisons. He states that the larva is able to reject arsenicals because of the closing mechanism in the buccal cavity. It is possible that other species of larvae in the same genus are able to do the same not only with arsenicals but with other objectionable compounds as well.

Fall and spring plowing for the control of wireworms in the Connecticut River Valley region of Massachusetts has not been very successful. Fall plowing has been recommended on the assumption that a high percentage of the larvae or the pupae may be exposed to unfavorable surface temperatures and weather conditions as well as predators. Spring plowing was supposed to have done the same to larvae. Observations in the field have shown, however, that the majority of the larvae and pupae may be below the plow line at the time of plowing and thus remain undisturbed. Larvae upturned by plowing in the spring may easily burrow back into the soil and thus escape unfavorable surface conditions.

The chief wireworm pests of the Connecticut River Valley in the vicinity of Northampton, Massachusetts, belong to the genera *Limonius*, *Ludius*, and *Melanotus*. The larvae of various species in these genera infest numerous crops including potatoes, tobacco, and truck crops. Potato seed pieces are often riddled by the larvae and re-planting is necessary. Injury to the tubers later in the season results in severe pitting. Tobacco sets are bored into by wireworms and the root thus destroyed. Heavy wireworm infestations necessitate as many as three settings in some regions. Truck crops, especially root crops such as beets, carrots, radishes and onions are destroyed if they are attacked early in the spring. Wireworm damage to the plants in the spring results in a definite loss to the grower in time, labor, and expense associated with the re-planting of the more seriously affected areas. Injury to crops later in the season, such as that to potatoes, materially reduces the value of the crop. Typical wireworm damage to potatoes in one area reduced the value of the crop about one-half. Damaged potatoes sold for fifty cents per hundred while the market price of U. S. number 1 potatoes at this time was one dollar per hundred. The grower estimated that the cost of growing this crop was seventy cents per hundred.

Limonius agonus Say, the eastern field wireworm, is the principal wireworm pest in the vicinity of Northampton, Massachusetts. Soil sampling revealed that this species inhabits the alluvial soils common in this region, particularly in fields bordering the banks of the Connecticut River. *Limonius agonus* and various species of *Ludius* were abundant in land that had been in cultivation for a number of years, while species of *Melanotus* were more common in sod and grass land. Rawlins (1940) has found larvae of the eastern field wireworm "almost exclusively in sandy types of soil" in upstate New York.

The presence and abundance of various species of wireworms was determined by soil sampling methods modeled after the work of Jones (1937). The unit sample of soil was one-fourth cubic foot (6 inches square taken to a depth of 12 inches). A one-fourth cubic foot soil sampler, constructed of steel and patterned after the one used by Jones (1937), was used to obtain the unit sample. When it was im-

[1] Notes from a thesis submitted to the faculty of the Entomology Department of the Massachusetts State College in partial fulfillment of the degree of Doctor of Philosophy.

[2] Contribution from the Department of Zoology and Entomology, North Carolina State College.

practical to use the steel sampler, the unit sample was measured on the soil surface, 6 inches square, and the soil to a depth of 12 inches was removed with a small garden trowel.

Treatment of the unit sample after it had been removed from the soil was as follows: a 2- or 3-inch layer of soil was removed from the sampler and placed in a sieve having a screen having four meshes to the inch. The soil was sifted by hand through this screen into a second, twelve-mesh, sieve. Any wireworms observed in this process were removed and recorded. The soil was then sifted through the finer screen. Although the process of sifting the soil twice was time-consuming, it enabled the worker to get all but the smallest wireworms out of the sample. By sifting the sample in successive layers, it was possible to determine the abundance of wireworms at various depths in the soil. The soil of the experimental plots was a sandy loam and no clogging of the screens was experienced except when samples of the grass land plots were sifted. The presence of roots in samples from sod areas tended to clog the finer mesh screen and frequent cleaning of the screen was necessary.

Fifty quarter-cubic foot soil samples, taken to a depth of 12 inches, were used as a basis for estimating the wireworm populations of experimental areas, two to four acres in extent. Jones (1937) states that "little practical effect upon the sampling error is obtained at any population level by using more than fifty units to determine the average number of wireworms per square foot of soil, but at least fifty units are necessary at low population levels." In the Northampton area, unit samples were taken at random throughout a plot, usually about 50 feet apart on a diagonal line across the field. Samples were taken on the opposite diagonal also.

Table 1.—Average number of wireworms per cubic foot, estimated acre population, and average depth of wireworms.[1]

Season	Average Number of Wireworms per Cubic Foot		Estimated Acre Population		Average Depth, Inches	
	1940	1941	1940	1941	1940	1941
Spring	7.3	6.3	317,988	274,428	4.6	7.5
Summer	5.4	5.8	235,224	252,648	7.0	7.4
Autumn	3.7	4.0	161,172	174,240	8.7	9.3

[1] Average depth estimated by adding the depths at which the wireworms in the fifty samples were found and dividing this total by the number of wireworms in the fifty samples.

Soil samples taken in the same area but at different seasons of the year formed the basis for estimating the seasonal population and depth of wireworms. Soil samples taken before and after treatment of the soil were used to determine the effectiveness of various methods of controlling wireworms. Soil sampling was also useful in estimating probable wireworm damage to plants as well as forecasting the possibility of wireworm damage to crops planted in new areas.

Wireworm populations in the experimental plots were estimated for the spring, summer, and autumn seasons. Few samples were taken in the winter because of the difficulty in digging in frozen soil. Fifty unit samples of one-quarter cubic foot size were taken in each plot during each of the three seasons. The results of this type of sampling in a typical experimental plot of the Northampton region are listed in table 1. For the purposes of this study, the period of time covered by the spring season included May to mid-June; the summer season, from July to late August (including the time of the potato harvest); the autumn season, late August (after potato harvest) to late September.

The difference in the average number of wireworms per cubic foot in the fall of 1940 and in the spring of 1941 was probably the result of sampling technique as well as changes in the size of wireworms at different stages of their life history. The wireworms taken at a depth deeper than twelve inches below the soil surface were not considered in these samples. No doubt many wireworms migrated below the twelve inch depth in the fall and reappeared above the twelve inch level at the time of the spring sampling. Furthermore, some wireworms were too small to have been counted at the fall sampling and some of these were probably included in the spring sampling.

The results of soil sampling, as listed in table 1, show that the wireworm population was higher in the spring than in the autumn of the same year. Hawkins (1936) states that there is a decrease of 45 per cent in the larval population from the spring to the fall. This decrease may be caused in part by the loss of some larvae through pupation. According to the data in table 1 there is a decrease of 49 per cent in the larval population from the spring of 1940 to the fall of the same year.

The decrease for the corresponding period in 1941 was 36.5 per cent.

Wireworms were nearer the soil surface in the spring than at any other season of the year. In the spring, wireworms in the cultivated areas are undergoing an upward migration in order to feed on the roots of newly planted crops. In the summer there is a downward migration of the larvae and this migration continues deeper in the autumn. High soil temperatures and consequent drying of the upper soil levels may be responsible for the downward migration in the summer while the cooler temperatures in this region during autumn may cause a continued downward migration during this season.

There was a greater abundance of wireworms in the low-lying and damper sections of the field than in the higher and drier areas. The species most common in the cultivated portions of the field was *Limonius agonus* while comparatively few specimens of *Ludius* and *Melanotus* were found here. MacLeod & Rawlins (1935) found larvae of *Limonius ectypus* and *Agriotes mancus* more abundant in low than in high areas.

Wireworm populations in sod areas differed markedly from those of cultivated areas, as is indicated in table 2. The average depth of the wireworms in the sod areas was 2 inches above that of the wireworms in the cultivated areas. The wireworm population of the cultivated area was approximately 74 per cent higher than that in the sod area.

Part of the experimental field had truck crops grown on it for about the past 5 years. The area adjacent to this truck crop section had potatoes as an annual crop for more than the past 5 years. These differently planted areas did not differ in topography or type of soil, nor was there any natural barrier between them. They did differ markedly, however, in their wireworm populations. The truck crop area had an estimated acre population of 66,696 wireworms and the potato area had 174,240 in the autumn of 1941. The lower population in the truck crop area was probably due to the cultural methods practiced. The soil in this area was cultivated much more frequently and cleanly than that of the potato area. In the truck crop area, the excess organic material was removed from the field before late fall plowing and there was no winter cover crop here. In the potato area, weeds, potato plants, and cull tubers were usually plowed under at the time of fall plowing. The area was then sown to a winter cover crop of rye.

Table 2.—Comparison of wireworm populations of sod areas and cultivated areas, autumn, 1941.

Area	Average Number of Wireworms per Cubic Foot	Estimated Acre Population	Average Depth Inches
Sod	2.3	100,188	7.0
Cultivated	4.0	174,240	9.3

It is believed that the differences in wireworm populations in these two areas are correlated with the differences in the cultural methods practiced in these areas. The removal of excess organic material and the disturbing factor of frequent cultivation may be responsible for the lower populations in the truck crop area. Conditions for wireworm development and corresponding increase in population of wireworms are more favorable in the potato area where organic matter is supplied not only by the plowing under of crop debris but also by the growing of a cover crop of rye, which is turned under in the spring.

The problem of chemical control of soil pests such as wireworms is a difficult one. The protection offorded by the soil to the larvae limits the use of contact insecticides as an effective control. The commonly used stomach poisons, such as the arsenicals, are not very successful apparently because the larvae reject them, as described by Woodworth (1938). Fumigants of various types have been used and these have been successful under certain conditions. The high cost of some fumigants may limit their use on a field scale but they can be used in small garden areas.

Dichloroethyl ether has been reported as a soil insecticide by Campbell & Stone (1937). Since that time, its use as a soil fumigant has been widespread. Stone (1942) reported on the use of dichloroethyl ether for control of the sugarbeet wireworm. Preliminary tests in the laboratory and in the field indicated that this compound had some promise as a control of wireworms under the conditions existing in the Northampton area.

Laboratory tests with dichloroethyl ether included the application of various concentrations of the compound to wire-

worms contained in cans measuring 6 inches in diameter and 9 inches deep. Larvae were held in small wire cages at various depths ranging from 1 to 6 inches in soil contained in the cans. A concentration of dichloroethyl ether, 1 cc. to 1000 cc. of water, applied at the rate of 1 pint per can, killed all wireworms from the 1- to the 5-inch levels but did not kill those at the 6-inch level. Stronger concentrations of 2.67 cc. to 1000 cc. of water, applied at the rate of 1 pint per can killed 50 per cent of the wireworms at the 6-inch level. One quart of this solution killed all wireworms at all depths down to and including 6 inches.

Dichloroethyl ether is not readily soluble in water. Various types of emulsifiers were used to emulsify the ether with the water. One cc. of a 50 per cent aqueous solution of *Aresklene* or *Ultrawet* was enough to emulsify the concentrations of dichloroethyl ether mentioned in this work. In most of the experiments, *Tergitol Penetrant 7* was used as an emulsifier at the rate of 1 cc. to 1000 cc. of solution. In preparing the emulsion, the *Tergitol Penetrant 7* was added to the required amount of ether and an equal amount of water. These materials were then shaken for about a minute and a white emulsion was produced. The emulsified ether was then added to the required amount of water.

The amount of moisture in the soil seems to influence the degree of wireworm control. Laboratory tests on the effectiveness of a concentration of dichloroethyl ether, 2.25 cc. per 1000 cc. water, applied to soils of different moisture content showed that a greater kill was obtained in dry soils than in moist soils. Very dry soil, that could be easily sifted through a 14 mesh screen, was compared with soil that could not be sifted through the screen. In the dry soil, the application of one pint of the dichloroethyl ether solution killed 83.3 per cent of the wireworms placed at a depth of 5 inches in the soil. In the nearly saturated soil, a kill of 20 per cent at the 5-inch depth was noted.

In the field, the effectiveness of dichloroethyl ether was proportional to the penetration of the solution when applied to the surface of the soil. Stone (1942) found that insufficient penetration of test solutions of dichloroethyl ether resulted in poor kill of wireworms at depths of 8 to 12 inches. In loose soils, such as that of potato hills of the Northampton plot, wireworms were killed as far down as 12 inches below the soil surface. In truck crop areas, where the soil was packed due to frequent weeding and cultivation, wireworms were seldom killed below a depth of 4 inches by the maximum surface applications considered practical. The use of dichloroethyl ether for wireworm control in the truck crop areas of the Northampton region, at least when applied by this method, cannot be recommended because of this poor penetrability.

It is possible that better kills in well packed soils can be realized by a different method of applying dichloroethyl ether than that described above. Abraham (1940) described an applicator used for forcible injection of carbon disulphide into the soil. The use of a similarly constructed applicator for injection of dichloroethyl ether at proper depths in the soil might be advisable for wireworm control, especially in well packed soil.

Although the penetration of the dichloroethyl ether was favorable in the loose soil of the potato hills, its use here is limited. At a concentration of 2.25 cc. to 1000 cc. water, applied at the rate of 1 quart of solution per potato hill, wireworms were killed to a depth of 12 inches. Treated areas, however, can evidently be re-infested within 6 days after treatment, indicating that the dichloroethyl ether at the 2.25 cc. per 1000 cc. water concentration does not remain repellent to wireworms for any great length of time. In order to keep potatoes free of wireworm injury, several applications of the dichloroethyl ether solution are necessary at short intervals throughout the growing season. From the standpoint of time and labor consumed, this is not a very efficient means of control. Another factor makes the repeated application of dichloroethyl ether to potatoes undesirable and this is the fact that the solution may impart a disagreeable flavor to potatoes. Tubers that had undergone one treatment six weeks before harvest time retained this flavor for several weeks after digging. Repeated applications of the ether gave a stronger flavor to the potatoes which lasted as long as five months after digging. Cooking did not rid the potatoes of this disagreeable flavor.

Stone (1942) reported that concentra-

tions of 3.5 and 7 ounces of dichloroethyl ether per 100 gallons of water applied to the surface of the soil at the rate of 1 to 1.4 gallons of solution to 1 foot of row immediately after seed potatoes were planted killed a considerable number of wireworms, particularly at depths of 4 to 8 inches. No effect was noted on the flavor of the treated potatoes.

Dichloroethyl ether at a concentration of 2.25 cc. per 1000 cc. water may cause premature yellowing of the potato foliage. Plants 12 to 14 inches high showed marked premature yellowing of the leaves within one week of being treated with the above solution at the rate of 0.5 to 0.75 quarts per hill. Repeated applications may cause severe yellowing of the leaves. Leaves dry up and tuber production is lessened. The yield of the potatoes in the treated areas was 44 per cent less than in the untreated check areas. Treated areas had 15 per cent more of small and cull potatoes than did the untreated areas.

It is of interest to note two methods of control tried by a grower in the Northampton area. In the autumn of 1940, the grower applied sulfur at the rate of 400 pounds to the acre without any noticeable control of wireworms. The sulfur was broadcast and then disced under. In 1941, tobacco stems were used in an attempt at control. The stems are the midrib of the leaf of the broadleaf type of tobacco commonly grown in the Northampton region of the Connecticut River Valley. The tobacco stems were broadcast over the field in the early spring at the rate of 200 pounds per acre. The stems were then disced under before the fields were planted. The grower had been informed by another farmer that this treatment would solve his wireworm problem. Sampling of the tobacco treated area throughout the year showed that the wireworm population had not been reduced by the treatment.

SUMMARY.—Larvae of the elaterid genera *Limonius*, *Ludius*, and *Melanotus* are destructive to the underground portion of certain truck crops and potatoes grown in the vicinity of Northampton, Massachusetts, situated in the Connecticut River Valley. Wireworm populations for the various periods of the year were estimated on a basis of 50 quarter-cubic foot soil samples taken to a depth of 12 inches in plots 2 to 4 acres in extent.

Sections of the field that had been in cultivation for a number of years had a higher larval population of *Limonius agonus* than of *Ludius* or *Melanotus* species. The wireworm population was much higher in cultivated areas than in grass land. In the plots that had been planted to truck crops or potatoes, respectively, for 5 consecutive years the former had lower wireworm populations than the latter. The smaller number of larvae in the truck crop area was probably due to the fall removal of crop residues from, the absence of a winter crop on, and the more frequent cultivation of that area as compared with the area planted to potatoes.

The control of wireworms with dichloroethyl ether, when applied to the surface of the soil as a dilute solution in water, is limited by the penetration of this material into the soil. Poor penetration of dichloroethyl ether under packed soil conditions of truck crop areas was noted. Although penetration and kill of wireworms by dichloroethyl ether was high in the loose soil of potato hills, its use here is limited because it imparts a disagreeable flavor to the tubers.—5-5-43.

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The Effects of Sulfur Residue on Keeping Qualities of Canned Tomato Products[1]

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Control of the potato and tomato psyllid, *Paratrioza cockerelli* (Sulc), is essential in successful tomato production in most parts of Colorado. List (1918, 1935, 1938, 1939) has shown that dusting sulfur, wettable sulfur and lime sulfur are the most effective control materials for this pest. As these materials leave a residue of elemental sulfur some have feared that the sulfur might carry over into the canned products in sufficient quantities to hasten spoilage. Much of the non-bacterial spoilage of canned fruits is caused by the fruit acid corrosion of the tin plate of the cans. This corrosion may be influenced by the presence of a number of materials. As hydrogen is a product of the corrosion the term "hydrogen swells" is used to denote a swelling or bulging of the can caused by an accumulation of hydrogen.

Vaurio *et al.* (1938) have developed a hydrogen evolution test as a means of evaluating the can service value of tin plate.

One of the materials thought to accelerate corrosion is sulfur, hence the fear of its use as an insecticide or fungicide on products to be canned. A number of workers have studied the electrochemical action of the corrosion. Among those who have contributed much to our knowledge of the action are Lueck & Blair (1928), Kohman & Sanborn (1929), Culpepper & Moon (1929), Vaurio *et al.* (1938). These workers rather generally agree that the tin coating protects the steel base of the tin plate electrochemically, because tin is anodic to steel in most food acids. This electrochemical action may vary with the different fruits and may be influenced by many materials. Clough *et al.* (1924) found by adding small quantities of lime sulfur to cans filled with gooseberries, that spoilage could be induced in a short time. Later experiments with gooseberries dusted with sulfur resulted in spoilage after 90 days. Work by Clough & Shostrum (1930) indicated that some sulfur compounds might have a beneficial effect when added to sweet cherry canned products.

Wiegand *et al.* (1936) found that the addition of elemental sulfur, sodium thiosulfate, and sodium sulfide at the rate of 10 ppm. of sulfur to canned prunes, produced extremely active corrosion, whereas sodium sulfate at the same rate gave a much less severe action. The corrosion that occurred in lots of prunes given orchard treatments of lime sulfur, wettable sulfur and dusting sulfur closely paralleled that observed in the respective control packs. Analyses showed that in all cases the sulfur residue on the fruit was less than 0.3 of one part per million parts of can content. Their conclusion was that the residues were not a serious factor in causing corrosion. The fact that sulfur was causing trouble in some canned fruit and the further fact that apparently no work on its possible effect in canned tomato products had been done were responsible for the experiment described in this article.

EXPERIMENTAL METHODS AND MATERIALS.—In psyllid control on tomatoes it is recommended that special attention be given to early season control. Where this is done it is seldom necessary to spray or dust after the fruit is well formed. However, knowing that late control may often be advisable when early work is neglected, a rather severe test of the residue factor was planned. Plots, in a field of the Landreth variety, were treated as described below 13 days before the first experimental harvest. These same plots were given a second treatment the day before the second experimental harvest and 21 days after the first treatment. Thus the first harvest material had one treatment after the fruit had begun to ripen and the second harvest material had two treatments. One treatment consisted of the undiluted dusting sulfur and a second of five quarts of the lime sulfur plus 5 pounds of wettable sulfur to 100 gallons of water. The entire field had been

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treated with sulfur dust early in the season, but not after the fruit had begun to form. The general harvest from the field was used as the check.

The materials used were dusting sulfur, wettable sulfur and liquid lime sulfur. The dusting sulfur and wettable sulfur had a fineness of 98 to 100 per cent through a 325-mesh screen. The liquid lime sulfur had a test of 32.5° Baumé. The dusting sulfur was applied by means of a rotary hand duster. Through an error the first application went on at the rate of 110 pounds per acre, an extremely heavy application. The second application was at the rate of 25 pounds per acre. The lime sulfur and wettable sulfur combination spray was applied by means of a barrel hand power spray pump, maintaining a pressure of approximately 125 pounds. The spraying was done by hand, using a single whirl pool type nozzle on a 4-foot rod. The first application was made at the rate of 103 gallons per acre and the second at 92 gallons per acre.

During the period between the first applications and the first harvest 0.62 inch of rain fell and during the period between the first harvest and second harvest 1.43 inches fell. As the season was somewhat abnormal many of the fruits were rather badly cracked about the stem end, thus making rough areas that probably held more than the usual amount of residue.

The fruits were taken to the factory in the late afternoon of the day they were picked and processed with the beginning of factory operations the next morning. The studies were limited to juice as it was thought that since the fruit for this product is not peeled it would be most likely to carry injurious amounts of sulfur. All tanks were empty each morning when the processing of the experimental fruit was started. From each lot of fruit sufficient samples were available to fill the 150-gallon break-down tank for continuous operation and in addition provide two 75-gallon tanks of finished tomato juice from which the can samples were taken.

The washing and processing were carried out as with the commercial packs. The fruit was first dumped into a soaking bath, the tank being about 3 feet in length filled with constantly changing water heated to a temperature of about 120° F. by a steam coil in the bottom of the tank. From this the fruit was lifted by a cleated belt and carried for a distance of about 3 feet under three banks of spray of warm water. Here obviously inferior fruits were discarded and the remainder dropped from the belt into a second wash tank. From this the fruits were again lifted and passed under a bank of three sprays before going onto the final sorting belt. To insure a careful examination the system required that each fruit be lifted by hand from the sorting belt to a final one going to the pulper. The process from this point was standard. The temperature of the juice at the time of sealing was approximately 180° F. The cans used were of the plain coke type. These are generally used for tomato juice in Colorado.

Fifty-ounce cans were used for all samples in which the "flip" type of test of the vacuum was made. Thirteen-ounce cans were used to supply material that could be opened at each examination period.

Table 1.—Treatments given and symbols used to designate the finished products.

Symbols for Storage Temperatures		No. Cans Used Each Temperature for "Flip" Test	Treatments
72°	98°		
C	CA	12	Lime-sulfur + wettable sulfur 13 days before harvest.
C2	C2A	12	Dusting sulfur 13 days before harvest.
C3	C3A	12	Check for C and C2 (first harvest).
C4	C4A	12	Check for C5 and C6 (second harvest).
C5	C5A	12	Dusting sulfur 21 days and 1 day before harvest.
C6	C6A	12	Lime-sulfur + wettable sulfur 21 days and 1 day before harvest.
C4-2	C4A2	6	2 ppm. sulfur added.
C4-4	C4A4	6	4 ppm. sulfur added.
C4-6	C4A6	6	6 ppm. sulfur added.
C4-10	C4A10	6	10 ppm. sulfur added.

The sulfur added in known amounts to cans was taken from the sample used in dusting the plots. The measured amount for each can was placed in a gelatine capsule which was dropped into the can just as it went into the sealer. Twenty-four 50-ounce and 48 13-ounce cans were selected at random to represent each field treatment. The known amounts of sulfur were in each case added to 12 50-ounce cans.

Each of the samples taken was divided into two lots, one for storage at 72° F. and the other for storage at 98° F. The 72° storage room was an inside room just off a thermostatically controlled laboratory in a brick building. The temperature was maintained near 72° except a few times in the summer when it went as high as 78° F.

The 98° storage conditions were provided in a large incubator box equipped with a fan. The temperature seldom varied more than one or two degrees from 98°. In order to compensate for any temperature differences that might occur in the box, the samples were randomized as to position following each examination.

Examinations were made at 3-month intervals. Two of the 13-ounce cans from each sample were tested for vacuum by means of a puncturing vacuum instrument and the pH reading taken of the contents. All empty cans are being saved for examination at the end of the experiment for evidence of staining or corrosion. Vacuum readings were taken on each of the 50-ounce cans without puncturing the cans. This was done by placing a can in a glass vacuum chamber and drawing a vacuum sufficient to "flip" the end of the can. Air was then allowed to slowly enter the chamber. The mercury column reading that was maintained as the lid gave its last distinct flip back to normal position was recorded in centimeters of mercury. The amount of external vacuum required to flip the end of a can having an internal vacuum is approximately equal to the internal vacuum plus the resistance of the lid. The average resistance of the lid as determined by using the vacuum instrument on 12 50-ounce cans sealed with tap water at a temperature of 68° F. and tested at this temperature was 13.23 centimeters of mercury. However, in these studies of the data the sum of the internal vacuum and the lid resistance is used. This seems logical as in the trade, spoilage, as indicated by loss of vacuum, is not considered to occur until internal gas formed overcomes the internal vacuum and lid resistance, thus causing the can to bulge. No corrections have been made for slight differences that may have resulted from variations in barometric pressure.

This paper deals only with a study made of the vacuum in the 50-ounce cans. The pH differences, which do not at this time appear significant, the vacuum in the 13-ounce cans, and the corrosion

Table 2.—Analysis of variance of vacuum that occurred in cans of tomato juice prepared from field treated plots and stored under temperatures of 72° and 98° F.

Source of Variation	Degrees of Freedom	Mean Square of Variance	"F" Values		
			Observed[1]	5%[2]	1%[2]
Treatments	2	3324.95	241.81	2.99	4.60
Harvests	1	6163.60	448.26	3.84	6.64
Temperature	1	36530.90	2656.79	3.84	6.64
Regression	1	12304.70	894.89	3.84	6.64
Treatment Regression Effect	2	3.08	.224		
Harvest Regression Effect	1	571.24	41.54	3.84	6.64
Temperature Regression Effect	1	8058.92	586.10	3.84	6.64
Residual	1286	13.75			
Total	1295				

[1] Observed $F = \frac{\text{Mean square for source of variation}}{\text{Residual Mean Square}}$

[2] When degrees of freedom are 1 and 1286 respectively, the value of F at P = 0.05 is 3.84; at P = 0.01 it is 6.64. When the degrees of freedom are 2 and 1286 respectively the value of F at P = 0.05 is 2.99; at P = 0.01 it is 4.60. Snedecor (1940).

effects on the cans will be discussed when the experiment is closed and all cans opened.

RESULTS.—The statistical analyses of the data taken on the vacuum as it occured over a period of 2 years, in the cans of material representing the field treatments, is given in table 2.

There are highly significant differences among treatments. It is difficult to see how the treatment effect could be so pronounced during the short period between processing and the initial examination. These differences appear to be due to a failure to control conditions. For example, the initial vacuum was dependent upon the temperature of the can contents at the time of sealing. While the cans were filled at 180° F. there were delays that influenced the sealing temperature. The principal delay came from the necessity for making certain changes in the sealing equipment so 13- and 50-ounce cans could be used at each experimental canning. The same explanation would hold for the significant difference that appears to be due to harvest.

There is a highly significant difference between storage temperatures. This can be explained in part by the fact that all samples were tested at their storage temperatures. The difference between the vacuum of cans at 98° and 72° was about 5.5 centimeters of mercury.

The remaining items in the table are the ones of importance. Variation due to the regression, or loss of vacuum is highly significant. However, the treatment regression effect is not significant. The sulfur residues from the treatments have not increased the rate of loss of vacuum. The harvest regression effect is significant. The experiment has not brought out an explanation of this. Temperature regression effect is highly significant. Temperature is by far the most important influence upon the regression and the results call attention to the importance of suitable storage temperatures for canned products.

The data show that to date the regression has been quite uniform during the entire period. It is recognized that this may not continue for all samples. Time may bring sudden losses of vacuum through a greater exposure of steel and a more rapid formation of hydrogen, or even through perforation. The vacuum regression study that follows is applicable to a uniform regression.

In studying the vacuum regression that occurred when known amounts of sulfur were added, the fitted regression equations are of the form $V = A_T + A_{2K} + (B_T + B_{2K})t$ where the subscripts denote: T = storage temperature; K = ppm. of sulfur added. σ = standard error of an individual observation = 5.33

$$\sigma A_T = \sigma B_T = \frac{\sigma}{\sqrt{216}} = 0.36$$

$$\sigma_{A_{2K}} = \sigma_{B_{2K}} = \frac{\sigma}{\sqrt{108}} = 0.51$$

$$A_{72^\circ} = 46.17 \quad A_{98^\circ} = 46.55$$

The values of A_{72° and A_{98° indicate, as might be expected, that the initial vacuum is independent of the amount of sulfur added. The initial vacuum reading was taken only a few days after the cans were filled. However, the initial vacuum was taken at the same temperature at which the cans were stored. A variation due to this could have been expected.

A determination of the variations that occurred in the initial vacuum of the cans carrying varying amounts of sulfur gives the following: $A2 = -1.99$, $A4 = 0.06$, $A6 = 0.46$, and $A10 = 1.47$.

The standard error of the difference $= \sqrt{2}(.51) = .72$. These differences are significant. It would appear that a greater amount of sulfur added results in a higher apparent vacuity. However, there seems to be no sound basis for this. It is possible that variations in the sealing temperatures could be responsible. The sulfur was added to all cans during one experimental canning; however, it was necessary to slow up the line and stop the sealer following the addition of each varying amount.

The difference in the effect of temperature of storage upon loss of vacuum is highly significant, since the following values $B_{72^\circ} = -.563$ and $B_{98^\circ} = -3.412$ were obtained. The vacuum loss under 98° storage is more than 6 times that under 72° storage.

A determination of the decreasing trend of the vacuum in the cans with varying amounts of sulfur gives the following: $B_2 = .518$, $B_4 = .353$, $B_6 = .197$, and $B_{10} = -1.06$. The standard error of the difference is $\sqrt{2}(.51) = .72$. Clearly the decreasing trend is significant in these regression coefficients and the conclusion that loss of vacuum is directly correlated

with the amount of sulfur added is evident and entirely justified.

The regression equations $V=A_T+A_{2K}+(B_T+B_{2K})t$ may be simplified to the form $V=a-bt$ and thus give:

72°

2 ppm. (C4- 2) $V=44.2-.004t$
4 ppm. (C4- 4) $V=46.2-.210t$
6 ppm. (C4- 6) $V=46.6-.366t$
10 ppm. (C4-10) $V=47.6-1.629t$

98°

(C4A2) $V=44.6-2.892t$
(C4A4) $V=46.6-3.058t$
(C4A6) $V=47.0-3.214t$
(C4A10) $V=48.0-4.477t$

The effects of both sulfur and storage temperature are clearly shown. The loss of vacuum is slow for storage at 72° with sulfur added up to 6 ppm. The loss with 10 ppm. of sulfur under 72° storage does not appear serious. It will be noted that almost complete spoilage could be expected when storage is at 98° after 2 years and 9 months when 10 ppm. had been added and after 3 years and 9 months when 6 ppm. sulfur had been added. These vacuum losses are shown graphically in Fig. 1. All regression lines start at the point of the average initial vacuum. The vacuum losses with 2, 4 and 6 ppm. of sulfur do not vary greatly with either temperature. Ten ppm. of sulfur brings about a marked increase in vacuum loss under both 98° and 72° F. storage temperature, yet the percentage loss under 72° does not appear serious for a 2 year storage period. The increase of the storage temperature from 72° to 98° F. brought about a greater vacuum loss in the check than occurred with 10 ppm. of sulfur under 72° F.

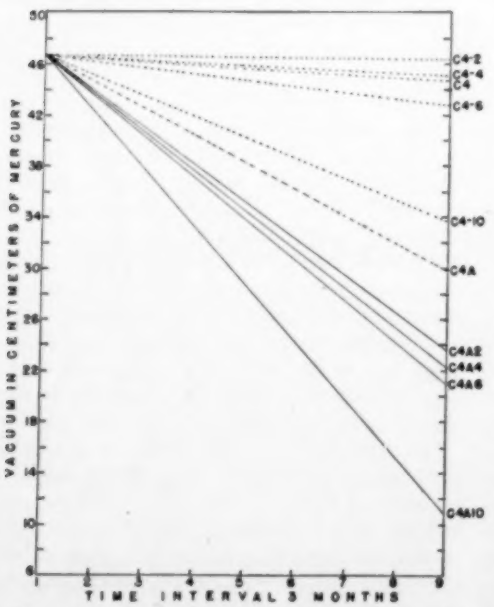

FIG. 1.—Vacuum regression in cans of tomato juice carrying varying amounts of sulfur and stored under temperatures of 72° and 98° F.

In making an analysis of the vacuum regression variation that occurs in the original experiment involving sulfur treatments the regression equations have the following form: $V=A_T+A_K+(B_T+B_K)t$ where the subscripts denote: T = temperature; K = treatments C, C2, C3, C4, C5 and C6.

σ = standard error of an individual observation = 3.753

$$\sigma A_T=\sigma B_T=\frac{\sigma}{\sqrt{648}}=0.1473$$

$$\sigma A_K=\sigma B_K=\frac{\sigma}{\sqrt{216}}=0.2551$$

$A_{72°}=50.46$ $A_{98°}=48.87$

The variation here could be accounted for by the difference in temperature of the materials when the initial vacuum readings were taken. Throughout the experiment the vacuum readings were taken at the storage temperatures.

The following are the variations that occurred in the initial vacuum of the samples representing field treatments: $A_C=-2.1$, $A_{C2}=-1.8$, $A_{C3}=-5.6$, $A_{C4}=-0.9$, $A_{C5}=+3.6$ and $A_{C6}=+6.8$.

This variation can again be explained by failure to maintain uniform sealing temperatures.

The difference in the effect of temperature of storage upon loss of vacuum is very evident. The equations $B_{72°}=-.327$ and $B_{98°}=-2.161$ show the loss of vacuum trend to be almost 7 times greater for 98° than for 72° F. This ratio in storage temperature effect is about the same as for the experimental results wherein various quantities of sulfur are added.

In making an analysis of the variation in vacuum trend in the samples representing field treatments we have the following: $B_C=+.146$, $B_{C2}=-.010$, $B_{C3}=+.500$, $B_{C4}=+.062$, $B_{C5}=-.250$ and $B_{C6}=-.447$.

The variation of treatments on trend of loss of vacuum is hardly significant. Treatment C6 seems to be the most serious in this regard.

The regression equations $V=A_T+A_K+(B_T+B_K)t$ may be simplified to the form $V=a-bt$ and we have:

72°

(C) $V=48.36-.181t$
(C2) $V=48.66-.337t$
(C3) $V=44.85-.72t$
(C4) $V=49.54-.265t$
(C5) $V=54.05-.577t$
(C6) $V=57.32-.774t$

98°

(CA) $V=46.76-2.015$
(C2A) $V=47.06-2.661t$
(C3A) $V=43.26-1.661t$
(C4A) $V=47.95-2.099t$
(C5A) $V=52.45-2.411t$
(C6A) $V=55.72-2.608$

The vacuum losses that occurred in the field treatment samples under conditions of 98° F. storage are shown graphically in figure 2 in comparison with the regression

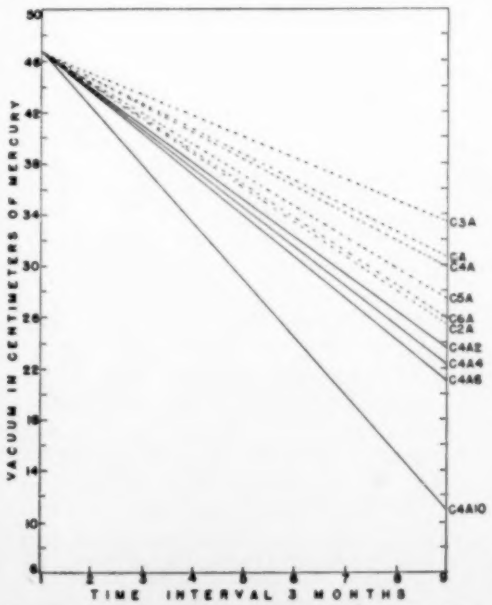

FIG. 2.—Vacuum regression in cans of tomato juice with varying amounts of sulfur added, compared with the regression in cans of juice from untreated and sulfur-treated field plots. All stored under temperature of 98° F.

trends of the sulfur added samples stored at the same temperature. It will be noted that the vacuum loss in all field treatment samples is less than that which occurred with 2 ppm. of sulfur, the smallest amount added. The variation in vacuum loss among the samples representing field treatments and their checks is not great, and is not significant statistically.

Figure 3 shows the regression lines of the field-treated samples in comparison

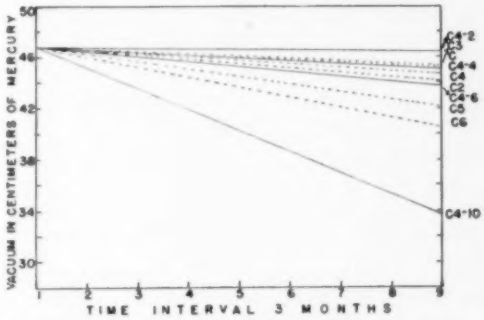

FIG. 3.—Vacuum regression in cans of tomato juice with varying amounts of sulfur added compared with the regression in cans of juice from untreated and sulfur treated field plots. All stored under temperature of 72° F.

with the regression trends of the sulfur-added samples stored at 72° F. The variation here is very slight and cannot be definitely attributed to the presence of sulfur from field treatments or from the addition of known amounts, with the possible exception of the sample having 10 ppm. of sulfur. Even this sample will not have complete vacuum loss for several years with the present trend of regression. A comparison of figures 2 and 3 again shows clearly the influence of temperature on vacuum loss.

SUMMARY AND CONCLUSIONS:—Storage temperature is a powerful influence in its effect on vacuum loss. The effect of 98° F. is more than six times that of 72° with the cans carrying known amounts of sulfur and almost 7 times that of 72° with the field plot material.

Increasing amounts of sulfur added increase the rate of vacuum loss when the storage temperature is 72° F. This loss is not serious with sulfur added up to 6 ppm. Under conditions of 98° storage a complete loss of vacuum can be expected after 2 years and 9 months when 10 ppm. of sulfur are added and after 3 years and 9 months when 6 ppm. are added.

An increase in storage temperature from 72° to 98° is a greater factor in vacuum loss than are the additions of 2, 4, 6 or 10 ppm. of sulfur.

Field treatment effects on vacuum loss, when the tomato juice is stored at either 72° or 98° F. temperature, appear negligible, with the harmful effect of C6, two treatments with sulfur dust after harvest had started, indicated but not statistically proved.

The data indicate that the use of two treatments of sulfur dust or two treatments of lime sulfur with wettable sulfur added, even after harvest has begun, does not present a sulfur residue problem of importance to the processor if the usual care in washing the fruit is taken.

It appears that the present general practices of tomato psyllid control on canning tomato planting through the use of sulfur can be continued safely.—5-24-43

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Rate of Application and Strength of Cryolite Dust Mixtures in Tomato Fruitworm Control

J. WILCOX, *U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine*[1]

Field experiments to obtain better control of the tomato fruitworm, *Heliothis armigera* (Hbn.), have been conducted in southern California since 1937. The results of the experiments of 1937 were summarized by Wilcox & Stone (1940).

During the course of these experiments to determine the degree of control obtained with various strengths and quantities of insecticide, it was observed that the economic value of control varied according to the percentage of damage, the value of the crop, and the cost of the insecticide and its application. It is the purpose of this paper to discuss these factors and their interrelationship.

[1] Credit is due the following workers, who have assisted with these experiments at various times: M. W. Stone, 1937 and 1938; L. J. McIntosh, 1938 to 1940; M. M. Barnes, 1937 and 1939–41; Arnold Mallis, 1938; A. F. Howland, 1941–42, and Milton Irvine, 1942.

Early in the investigation cryolite was found to be one of the most promising insecticides for the control of this insect on tomatoes. Although other insecticides, especially calcium arsenate, have shown promise and other experiments with cryolite have been conducted, the discussion presented herein has been limited to the experiments in which various rates per acre and various strengths of cryolite were used.

METHODS.—The treatments were assigned at random to plots within a block. The plots, ranging in size from 0.025 to 0.5 acre, were at least 6 rows wide and 50 feet long. The rows were from 5 to 8 feet apart. The dusts were applied with rotary hand dusters, and both sides of each row were dusted at each application. In general, three applications were made,

the first when the first fruit of the main crop was setting and the second and third at 2-week intervals. The rates per acre and the timing of applications in most of the experiments are shown in table 1.

In estimating the cost of dusting, a grower's estimate of 6 hours' labor at 31 cents per hour for making three applications with a total of 75 pounds of dust per acre is used, together with our own experience gained in dusting several hundred acres of tomatoes with hand dusters. Up to a total rate of 90 pounds per acre for three applications it is estimated that the actual amount of walking is the same, *i.e.*, the adjustment on the duster will take care of the different amounts applied. For each 30 pounds of dust applied above 90 pounds per acre, 1 hour is added to the time required for application, as it is necessary to walk more slowly in order to apply the heavier rates per acre. For each 10 pounds of dust (a dusterful) it is estimated that it will take 10 minutes to walk back to the dust supply, fill the duster, and return to the place in the field where the dust ran out. On this basis, the number of hours required and the cost of dusting are shown in table 2.

Table 1.—Rate per acre and timing of applications of cryolite dust in tomato fruitworm control experiments in southern California, 1940 and 1941.

Total Application per Acre	Individual Applications per Acre					
	First Week	Second Week	Third Week	Fourth Week	Fifth Week	Sixth Week
Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
30	5	—	10	—	15	—
60	5	5	10	10	15	15
	10	—	20	—	30	—
	—	10	—	20	—	30
90	7.5	7.5	15	15	22.5	22.5
	15	—	30	—	45	—
	—	15	—	30	—	45
120	10	10	20	20	30	30
	20	—	40	—	60	—
	—	20	—	40	—	60
150	12.5	12.5	25	25	37.5	37.5
	25	—	50	—	75	—
	—	25	—	50	—	75

The results of the treatments were checked by picking all the fruit from five or more plants selected at random from the central part of each plot. The fruit was picked at the various picking times throughout the season so that the total crop was obtained from these plants. The total number of marketable fruits plus the number of fruits rendered unmarketable by the tomato fruitworm were used in determining percentages of damage. Tomatoes damaged superficially by the tomato fruitworm or injured by other insects were not included in the total damage attributed to the tomato fruitworm.

Table 2.—Time required for and cost of making three applications of cryolite dust at several total rates per acre, for control of the tomato fruitworm in southern California, 1940 and 1941.

Total Rate per Acre	Time Required			Cost at 80.31 Per Hour
	For Dusting	For Filling Duster	Total	
Pounds	*Hours*	*Hours*	*Hours*	*Dollars*
30	5	0.5	5.5	1.71
60	5	1.0	6.0	1.86
90	5	1.5	6.5	2.02
105	5.5	1.75	7.25	2.25
105[1]	10	1.75	11.75	3.64
120	6	2.0	8.0	2.48
150	7	2.5	9.5	2.95
180	8	3.0	11.0	3.41

[1] This estimate is for six applications at weekly intervals.

The experiments were replicated from 2 to 6 times in the various fields, and the results from the same series of experiments in different fields were combined at the end of the season. In general, it was found necessary to replicate the experiments 10 or more times before it was possible to show significant differences between treatments.

STRENGTH OF CRYOLITE USED.—Previous experiments reported by Wilcox and Stone (1940) have indicated that control was increased as the strength of cryolite was increased. In 1938, experiments were conducted in which several strengths of cryolite were used, and, although the results were not significantly different, the control obtained with a mixture of 70 per cent cryolite and 30 per cent talc was so much better than that obtained with weaker mixtures that 70 per cent cryolite was recommended for general use (White 1939). The results of one of the tests of 1938 are shown in table 3.

In 1939 the three brands of cryolite then on the market were tested at undiluted and at 70 per cent strengths.[1] The undiluted cryolites contained 93, 90, and

[1] Percentages of cryolite given here and hereinafter in this paper refer to percentages of sodium fluoaluminate.

Table 3.—Damage to tomato fruits in southern California by the tomato fruitworm following dusting with different dilutions of cryolite dusts applied at the same rates per acre, 1938 and 1939.

Dust Used	Total Amount per Acre for Entire Season		Fruits Damaged	Reduction in Damage
	Planned	Applied		
	Pounds	*Pounds*	*Per Cent*	*Per Cent*
Experiment in 1938, 6 Replicates				
Cryolite 70%, tale 30%	60	63	3.1	77
Cryolite 50%, tale 50%	60	59	5.2	61
None	None	None	13.4	—
Difference required for significance			2.5	
Experiment in 1939, 20 Replicates				
Cryolite No. 1, undiluted	60	61	3.1	79
Cryolite No. 2, undiluted	60	58	3.5	76
Cryolite No. 3, undiluted	60	62	3.7	75
Cryolite No. 1, 70%	60	60	3.5	76
Cryolite No. 2, 70%	60	61	4.0	73
Cryolite No. 3, 70%	60	59	4.8	67
None	None	None	14.6	—
Difference required for significance			1.1	

85 per cent of sodium fluoaluminate for brands Nos. 1, 2, and 3, respectively, and this was considered a fair basis for comparison, as the cost per pound was the same. When each was diluted to contain 70 per cent of sodium fluoaluminate the price per pound for brand No. 2 was slightly higher than for brand No. 1, and the price per pound of brand No, 3 was slightly higher than that for brand No. 2. The results of this experiment are shown in table 3. The three brands of cryolite gave practically the same degree of control. An average of 3.4 per cent of the fruits in the 60 plots dusted with the undiluted cryolites were damaged by the fruitworm, whereas in the 60 comparable plots dusted with the 70 per cent strength 4.1 per cent were damaged. The difference of 0.7 per cent in favor of undiluted cryolite is of mathematical significance but, considering the additional cost of the undiluted material, the advantage in using it is not great.

In the 1940 and 1941 seasons, experiments were conducted in which dusts containing 35, 50, and 70 per cent cryolite were used, but the applications were made at the same rate of sodium fluoaluminate per acre. The total amount of sodium fluoaluminate applied per acre for each dilution was 63 pounds. The results of these experiments are shown in table 4. As there was no significant difference between the percentages of fruits damaged for these three dilutions of cryolite, it was concluded that the cheapest dust, *i.e.*, the 70 per cent dust, was the most practical. The cost of the various dusts was estimated as follows: 180 pounds of 35 per cent dust, $10.05; 126 pounds of 50 per cent dust, $9.24; and 90 pounds of 70 per cent dust, $8.70.[1] In addition, the cost of application would be higher for the weaker dusts (Table 2).

Table 4.—Damage to tomato fruits in southern California by the tomato fruitworm, following dusting with different dilutions of cryolite dust applied at the same rate of sodium fluoaluminate per acre, 1940 and 1941.

Dust Used	Total Amount Per Acre For Entire Season		Fruits Damaged	Reduction in Damage
	Planned	Applied		
	Pounds	*Pounds*	*Per cent*	*Per Cent*
Experiment in 1940, 12 replicates				
Cryolite 35%	180	178	1.5	77
Cryolite 50%	126	127	2.2	66
Cryolite 70%	90	91	2.0	69
None	None	None	6.5	—
Difference required for significance ($P = 0.05$)	—	—	0.9	—
Experiment in 1941, 12 replicates				
Cryolite 35%	180	182	2.6	71
Cryolite 50%	126	129	2.7	71
Cryolite 70%	90	91	2.9	69
Cryolite 90%	76	77	2.8	69
None	None	None	9.0	—
Difference required for significance ($P = 0.05$)	—	—	1.1	—

On this same basis, 70 pounds of undiluted cryolite containing 90 per cent of sodium fluoaluminate would be equivalent to the above mixtures in sodium fluoaluminate content and would cost $8.05. The cost of application would also be somewhat less (Table 2). Unfortunately in 1941 (Table 4) the undiluted cryolite was applied at a total rate of 77 pounds per acre, rather than at 70 pounds per acre, but it seems likely that the results would not have been different if 7 pounds less dust per acre had been used. The advantages of using an undiluted dust over a diluted dust are: (1) The cost of mixing

[1] The cost of the dust was estimated as follows: 90 per cent cryolite (undiluted) at 11½ cents per pound; talc at 1 cent per pound; and mixing at 50 cents per 100 pounds.

and of diluent are eliminated, and (2) the labor for application or cost of application is less. In these experiments 20, 56, and 110 pounds of talc were applied per acre in the 70, 50, and 35 per cent dusts, respectively, without any apparent benefit from its use.

RATE PER ACRE.—A series of experiments conducted in 1940 and 1941 was designed to test the effectiveness of 70 per cent cryolite at several rates per acre in each of 3 schedules of application (table 1). Disregarding the schedules for the moment and combining them at the same rates per acre, the data for the experiments of 1940 and 1941 are shown in table 5. In 1940 the experiments were replicated 11 times, with a total of 33 replicates for each rate per acre. One hundred twenty pounds and 90 pounds per acre gave significantly better results than 60 pounds per acre, but the results from 120 pounds were not significantly better than from 90 pounds per acre. In 1941 (table 5) the experiment was replicated 9 times, with a total of 27 replicates for each rate per acre. One hundred fifty pounds per acre gave significantly better control than all other rates per acre. Although both 120 and 90 pounds gave significantly better control than 60 pounds per acre, there was no significant difference between the results from 120 and 90 pounds per acre. These results were corroborated in 1942 in an experiment in which the different quantities of cryolite were applied in only one schedule, namely in 3 applications at 2-week intervals. In addition to a check treatment, 120, 90, 60, and 30 pounds per acre were tested. The resulting percentages of fruits damaged by the fruitworm were 15.2 for the check, and 3.8, 4.7, 6.1, and 8.5, respectively, for the 4 rates. The difference required for significance was 1.4 per cent, showing that 30 pounds gave results inferior to 60 pounds, which in turn gave results inferior to 90 pounds per acre. These data indicate that at 30-pound intervals between 0 and 150 pounds per acre better control will result from each increase, except between 90 and 120 pounds per acre.

SCHEDULES OF APPLICATION.—Under rates per acre it was indicated that each rate of application was applied at three schedules of application. These schedules were: (1) Six applications at weekly intervals; (2) three applications at 2-week intervals at the first, third, and fifth weeks; and (3) three applications at 2-week intervals at the second, fourth, and sixth weeks. The average total rate per acre for each schedule was 105 pounds. The results of these experiments for the 1941 season are shown in table 6. It should be noted that schedules 1 and 2 are significantly better than schedule 3; in other words 1 week's delay in beginning the application gave decidedly inferior control. With a crop value of $400 and 12.1 per cent of damage in the untreated plots, the potential loss per acre from fruitworm damage in these fields was $48.40. Estimating the cost of dusting as shown in table 2 and the cost of 70 per cent cryolite as 9.67 cents per pound, the net profit per acre from dusting is shown in the last column in table 6. From these figures it is concluded that three applications made at 2-week intervals are more profitable than six weekly applications.

Table 5.—Damage to tomato fruits in southern California by the tomato fruitworm, following dusting with different total amounts per acre of cryolite-dust mixture containing 70 per cent of sodium fluoaluminate (1940 and 1941).

TOTAL AMOUNT PER ACRE FOR ENTIRE SEASON		FRUITS DAMAGED	REDUCTION IN DAMAGE
Planned	Applied		
Pounds	*Pounds*	*Per Cent*	*Per Cent*
Experiment in 1940, 33 replicates			
120	130[1]	1.5	81
90	98[1]	1.7	79
60	65[1]	2.2	72
None	None	8.0[2]	—
Difference required for significance ($P=0.05$)		0.5	—
Experiment in 1941, 27 replicates			
150	152	1.5	88
120	120	2.4	80
90	92	2.5	79
60	60	3.6	70
None	None	12.1[2]	—
Difference required for significance ($P=0.05$)		.56	—

[1] The rows in the first fields of this experiment were 6.5 feet apart and in the third field 5 feet apart, so the applications in the third field were made at the same rate per row as in the first two fields, resulting in a higher average rate per acre. On a row basis the dusts were applied at 120, 91, and 60 pounds per acre, respectively.

[2] Only one-third as many replicates were made as for the other treatments, and the difference required for significance does not apply. Separate analysis in each case demonstrated a highly significant difference between the treated and untreated plots.

Table 6.—Damage to tomato fruits in southern California by the tomato fruitworm, after dusting with an average of 105 pounds of 70 per cent sodium fluoaluminate per acre at several schedules of application, and net profit therefrom (1941).

Schedules of Application	Total Amount per Acre for the Entire Season		Fruits Damaged	Reduction in Damage	Profit per Acre after Deducting Cost of Dusting	
	Planned	Applied			Observed Mean Value	Expected Range in Value[1]
	Pounds	*Pounds*	*Per Cent*	*Per Cent*	*Dollars*	*Dollars*
6 weekly applications	105	105	2.2	82	25.90	24–28
3 2-week applications at 1–3–5 weeks	105	106	2.3	81	26.80	25–29
3 2-week applications at 2–4–6 weeks	105	106	3.1	74	23.42	21–25
None	None	None	12.1	—	—	—
Difference required for significance ($P=0.05$)	—	—	.5	—	—	—

[1] Based on a probability of 5 per cent.

Some Economic Factors Affecting Rate and Strength of Applications.—The previous experiments have indicated (1) that undiluted cryolite is superior to 70 per cent cryolite when applied at the same rate per acre; (2) that undiluted cryolite is as effective as 35, 50, and 70 per cent cryolite dusts when the applications are made at the same rate of sodium fluoaluminate per acre, and the cost per acre of undiluted cryolite is less; (3) that 150 pounds per acre of 70 per cent cryolite is superior to 120, 90, 60, and 30 pounds per acre; and (4) that three applications applied at 2-week intervals are less effective but more economical than six applications applied at weekly intervals. Combining these results and keeping within the limits of the experiments, it can be concluded that the best and most economical control should be obtained by making three applications of 70 per cent cryolite at 2-week intervals, using a total of 150 pounds per acre.

A study of some of the factors that have a bearing on whether it is economical to use the most effective control measure available indicates that in many cases the cost is not justified by the amount and value of the crop saved. Using the experiment of 1941 (table 5) as an example for the determination of the most economical treatment, the crop value per acre was estimated to be $400, which would allow a potential loss of $48.40 from fruitworm damage, with an average rate of damage of 12.1 per cent. Estimating 70 per cent cryolite at a cost of 9.67 cents per pound and the labor for application as shown in table 2, the profit from dusting at the several rates per acre is shown in table 7. Examination of table 7 discloses that under the conditions of this experiment, 90 pounds per acre is the most economical rate to use, and that even 60 pounds per acre is more economical than 150 pounds per acre.

Table 7.—Profits from dusting for control of the tomato fruitworm in southern California in 1941, using several rates per acre of 70 per cent sodium fluoaluminate.

Total Dust Used Per Acre for Entire Season	Fruits Damaged	Reduction in Damage	Profit Per Acre After Deducting Cost of Dusting	
			Observed Mean Value	Expected Range in Value[1]
Pounds	*Per Cent*	*Per Cent*	*Dollars*	*Dollars*
152	1.5	88	24.94	23–27
120	2.4	80	24.64	23–27
92	2.5	79	27.32	25–29
60	3.6	70	26.22	24–28
None	12.1	—	—	—

[1] Based on a probability of 5 per cent.

In the experiment on which table 7 is based, the crop was valued at $400 per acre and the average damage in the undusted plots was 12.1 per cent. Since 12.1 per cent of $400 is $48.40, the potential crop loss by the tomato fruitworm was about $48 per acre. Under the conditions of this experiment a perfect control could yield a profit of only $48 less the cost of control. In general, the experiments with cryolite and other insecticides indicate that, although the profit is dependent on the potential crop loss, the percentage of control is not materially affected by this factor.

For the purpose of determining the

most economical rates of application for the range of conditions that might be encountered, yields per acre have been estimated at from 5 to 20 tons and the value per ton at from $10 to $40, making a range in crop value of from $50 to $800 per acre. Damage by the tomato fruitworm is sometimes as high as 25 per cent and, considering the range in damage at from 5 to 25 per cent, the potential range in crop loss is estimated at from $2.50 to $200 per acre. From this range, and from the costs and percentages of control previously given for the different rates of application, the corresponding profits have been calculated. Applications of cryolite are not justified when the potential crop loss is from $2.50 to $7.50 per acre; 30 pounds is the most economical rate when this loss is from $10 to $20 per acre; 60 pounds when it is $30 per acre; 90 pounds when it is from $40 to $70 per acre; and 150 pounds when the potential loss is from $80 to $200 per acre.

In general in southern California, except under conditions of very light infestation of the tomato fruitworm, 90 pounds per acre is the most economical rate of application.

CONCLUSIONS.—Experiments conducted in southern California during the last 4 years have indicated that undiluted cryolite (90 per cent) is more effective against the tomato fruitworm than 70 per cent cryolite applied at the same rate of application of dust mixture per acre; but that it is approximately of the same effectiveness as 35, 50, and 70 per cent cryolite dusts when the applications are made at the same rate of sodium fluoaluminate per acre.

Experiments with dosages of 30, 60, 90, 120, and 150 pounds of 70 per cent cryolite per acre demonstrated that the effectiveness is correlated with the dosage. However, the differences in degree of control were not great and, considering costs and the value of the crop saved, the higher dosages in many cases would not be justified. Since tomato fruitworm damage in fields to which control measures are applied ranges from 5 to 25 per cent and the crop value may range from $50 to $800 per acre, it is estimated that the potential crop loss may range from $2.50 to $200 per acre and the most profitable rate of application will vary accordingly. When the potential crop loss or damage is less than $7.50 per acre no treatment seems to be justified; but when it is between $10 and $20 per acre, 30 pounds per acre is the most profitable rate of application for 70 per cent cryolite. Approximately 60 pounds is the best dosage when the potential damage is $30 per acre, 90 pounds when it is from $40 to $70 per acre, and 150 pounds when the potential damage is from $80 to $200 per acre.

Three applications of 70 per cent cryolite applied at 2-week intervals are not quite so effective but are more economical than six applications at weekly intervals. —5-5-43.

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ERRATUM

Journal of Economic Entomology, volume 36, No. 4, August, 1943, page 574; table 1, under *Aedes* lines indicated below should be substituted for lines as printed in the table:

GENUS AND SPECIES	Florida	Georgia	Alabama	Mississippi	Louisiana	Arkansas	Tennessee	North Carolina	South Carolina
canadensis	x	*	*	x	x	x	x	x	x
cinereus		*			?	x			*
dorsalis					?				
dupreei	x	*	P	*	x	x	P	x	x
fulvus pallens	x	x	P	x	x	x	P	x	x

The Tomato Russet Mite, *Phyllocoptes destructor* Keifer: Its Present Status

S. F. Bailey[1] and H. H. Keifer[2]

Since this new pest has been studied for a period of only three seasons, many facts concerning it are still unknown. Therefore, this report presents only the data accumulated from May, 1940, to November, 1942.

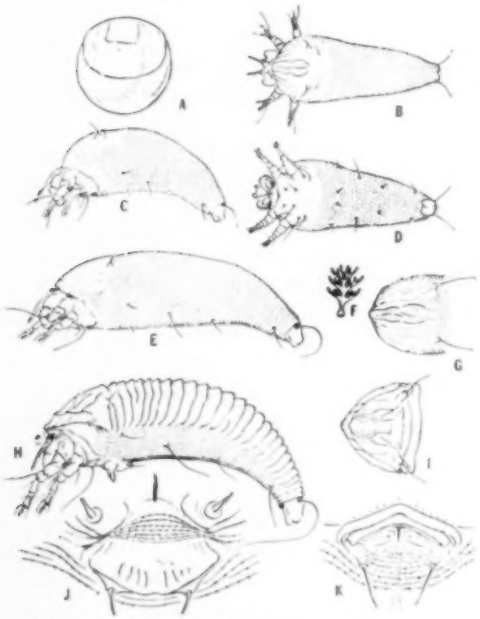

Fig. 1.—Camera-lucida drawings of the various stages of tomato russet mite.
A—Egg of *P. destructor*.
B—First-stage nymph dorsal diagram.
C—Same, side.
D—Same, ventral diagram.
E—Second stage nymph side view.
F—Adult featherclaw from below.
G—Second-stage nymph showing cephalothoracic shield pattern.
H—Adult female, side.
I—Cephalothoracic shield of adult.
J—Female genitalia.
K—Male genitalia.

History.—*Phyllocoptes destructor* was discovered by Bailey in a Modesto, California, hot house on May 10, 1940. The type specimens (Keifer 1940) were collected there June 27, 1940. Inspection of field tomatoes in the Modesto vicinity at that time failed to disclose infestations. On August 7, 1940, R. B. Auer found a severely infested field three miles northwest of Broderick, Yolo County. It was later found elsewhere as listed below. The mite cannot have been in California much earlier than 1940 since the violence of its attack on tomatoes quickly calls attention to its presence. Its mode of entry into California is unknown.

Origin.—The original area inhabited by the mite and its original Solanaceous hosts are unknown. The home of the species has at least a subtropical climate. The species is found in Australia[3] which might be its original habitat. The tomato plant as it is grown in California, and probably the ancestors of this type of plant, cannot have been the original host of the mite. Since eriophyids must depend on agencies beyond their control for traveling, they spread from host to host by chance. This means that the mites must have a perennial host which can survive the effects of their feeding, on which to base their seasonal development. In addition, this mite can feed and reproduce on a considerable range of solanaceous plants, with cultivated tomato the only one known to be killed outright.

Description.—The egg (Fig. 1 A) of *Phyllocoptes destructor* is spherical, 55μ in diameter, with a distinct cap. When first laid it is opalescent-white, later more cloudy and yellowish.

The first nymph (Fig. 1 B, C, D) attains a maximum length of about 90 to 100μ; translucent white; somewhat clavate in shape anteriorly. The beak is nearly the size of the adult beak. There are two pairs of cephalothoracic legs present as in the adult. The body is eriophyes-like in surface sculpture. The first nymph is unlike the two succeeding stages not only in size, but the cephalothoracic dorsal setae point up and forward, and the abdominal dorsum immediately behind these setae lacks rings and microtubercles.

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[2] Associate Systematic Entomologist, California Department of Agriculture.

[3] *Phyllocoptes lycopersici* Massee was described from tomato in Australia. The original description of *destructor* carried a comparison of *destructor* with *lycopersici* as described. The presence of *destructor* in Australia would indicate that there are three taxonomic possibilities: 1. That *lycopersici* varies more than most Eriophyids and both names apply to one species; 2. That the original description of *lycopersici* is incorrect and both names apply to one species; 3. That there are two species. We are not prepared to admit the first two propositions.

The second nymph (Fig. 1 E, G) grows to about 140 to 160μ or more in length; color more yellowish. Dorsal setae on rear of cephalothoracic shield and pointing caudad; abdomen eriophyiform, completely beset with rings and microtubercles. As in the first nymph the genital setae are present on the anterior venter of the abdomen, but no genital organs are present on the surface. The transforming stage at the end of the second nymphal instar is large enough to develop the adult. It is partially translucent.

Adult mite (Fig. 1 F, H, I, J, K) wedge-shaped, tapering posteriorly; male 150 to 200μ long; female about 200μ long and 50μ thick. Adult color yellow-orange. Cephalothoracic shield characteristically sculptured, shortly overhanging beak. Abdomen with rather broad smooth dorsal back plates or half-rings, somewhat flattened above and forming a slight subdorsal longitudinal ridge; ventral half-rings narrow and microtuberculate; genitalia located just behind coxae, the female genital coverflap furrowed. The posterior end of the abdomen bears a pair of large lobes for clinging and a pair of long hairs.

The mite is characterized largely by the short anterior lobe of the shield over the beak and by the shield sculpturing. The usual *Phyllocoptes* spp. have an anterior shield lobe which is extended farther ahead and more attenuate. We have seen no other similar mite in California nor does another Eriophyid species occur on Solanaceous plants on the west coast of North America to our knowledge.

HOSTS AND DISTRIBUTION.—*Phyllocoptes destructor* is found in Australia on tomato. In the Hawaiian Islands, as well as being found on tomato, the mite lives on popolo, *Solanum nodifolium* (submitted by Dr. C. T. Schmidt). The California hosts on which the mite is known to reproduce are: tomato, petunia, potato, nightshade, *Solanum nigrum* and *S. villosum*, the tomatillo, *Physalis ixocarpa*, *Datura stramonium* and *D. ferox*. The last three hosts are annuals. Recent literature indicates the presence of the tomato russet mite in Spain.

The mite develops most profusely and destructively on round red fruiting varieties of tomato. Petunia is at times noticeably damaged. Both of these plants are somewhat hairy or glandular, which condition produces a more favorable habitat for the mite. Excessively sticky varieties of petunias seem immune. The yellow pear tomatoes have so far proven resistant to the extent that they do not even show any mite population. An occasional red fruiting tomato plant has been observed which was undamaged and was probably resistant. Potato harbors many mites but apparently does not suffer as much damage as tomato.

The nightshades and daturas are in the main less favored hosts, perhaps largely due to the glabrous surfaces characteristic of most of these. There is much individual variation among black nightshade plants in respect to the development of the mites thereon. A specimen of nightshade from Ventura County, presumably *S. villosum*, with hairy leaves had the heaviest mite population yet seen on one of these plants.

Casual non-solanaceous hosts such as morning-glory, may bear adult russet mites in infested tomato fields, but no reproduction has been observed on these plants.

The chronological spread of the mite in California (Keifer 1941a, b, 1942; Lockwood 1941; Pacific Rur. Press, 1942) from county to county is: 1940—Stanislaus, San Joaquin, Sacramento, Yolo, Alameda; 1941—Contra Costa, Santa Clara, Fresno, Tulare, Kern, Solano, Napa and Yuba; 1942—Calaveras, Sonoma, Los Angeles, Orange, San Diego, Riverside, Ventura, Santa Barbara, San Luis Obispo, Imperial, San Bernardino, Monterey, Santa Cruz, and Butte.

INJURY.—The injury caused by this mite gave it the common name by which it is perhaps best known—the tomato russet mite. The typical injury first appears on the tomato stalk at the ground level whence it spreads upwards. The surface feeding produces a bronzing or russeted appearance on the surface of both stems and leaves. The density and shade of the brown color seems to be determined by the variety, the rate the injury is produced, and the temperature. Three or four weeks after having been injured the main stalk of the plant cracks or checks. The leaves turn brown and paper-like but do not wilt as in the case of some plant diseases.

The fruit is attacked only in the most severe cases. In the original infestation in

the hot house, the fruit was badly russeted (Fig. 2). In the field, mites are commonly found on the green fruit, particularly around the stem, but very little reproduction occurs on the fruit itself. The mites are rarely found in the flowers and do not injure them.

From the commercial standpoint the principal injury is from the loss of foliage

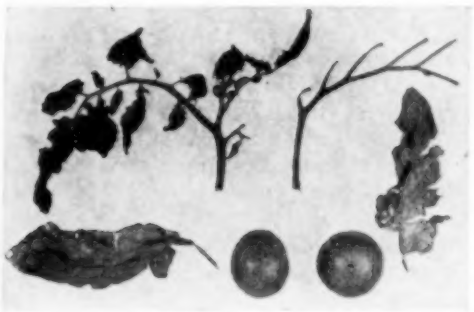

FIG. 2.—Injury to hothouse-grown tomatoes by the tomato russet mite. The stalk assumes a brown, dusty appearance and the leaves become dry and paper-like. Note the russeted fruit in the lower center.

which results in sunburning of the lower fruit. If no control measures are practiced, the entire vine turns brown and dies. The first signs of injury are evidenced by the russeting of the lower leaves and the "breaking open" of the vines in the center. Under such conditions weed growth in the field is an advantage since the exposed fruit is shaded. Later in the season, particularly after the second picking, the mites do have a minor point in their favor in that the exposed fruit of injured vines ripens quicker in the cooler weather of October.

Injury first appears on individual plants or in very small areas the last of June and it is usually about the middle of July before growers observe the familiar brown patches which are the indication of the mite infestation. From these focal points the infestation usually fans out in the direction of the prevailing wind and by the first picking has increased its spread considerably. During the operations of the first picking the mites are scattered by the dragging of the boxes over the vines, the rolling over of the plants, etc., and the injury the following two weeks can be seen throughout the greater part of the field. Badly infested fields frequently lose from one-third to one-half the crop from this pest. Where no control is practiced and the mites get an early start, a total loss may occur.

During 1940 it was conservatively estimated that about 500 acres were badly damaged. In 1941 the spread was so rapid it was difficult to keep up with the treatments but it is known that over 10,000 acres of tomatoes were dusted for this pest in and around the Sacramento-Stockton area. While the 1942 season is not yet over as this is written, the infestations extend over even a greater area and over 200 tons of dust will have been applied for this pest.

In contrast with other tomato Arthropod pests, the mite is by far the most serious. The horn worms are of minor importance and are readily controlled. The corn ear worm varies in its importance in certain areas; in the interior tomato-growing districts (where the mite is particularly abundant) it is of little concern. The pin worm appears to be largely limited by the colder winters in northern California and causes very little injury as compared with southern California. All of these pests cause widely-varying degrees of loss to the fruit. The tomato mite, if not controlled, will kill vines themselves.

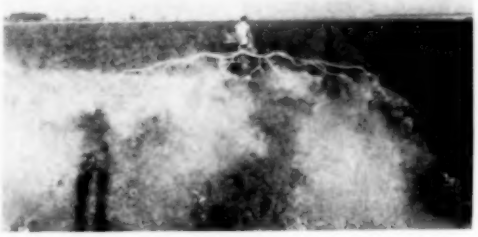

FIG. 3.—An example of an excellent application of dust by a 5-row crop duster. Note the good coverage on the portion of the field at the left. This application was at the rate of 30 pounds per acre of a mixture of 25 per cent sulfur and 75 per cent calcium arsenate.

LIFE HISTORY AND HABITS.—The development of the individual mites is rather simple. In the field continuous reproduction takes place from early May to November or until frost. The eggs are deposited irregularly among the hairs or in

slight crevices on either leaf surface, on the stems, and even on the smooth fruits in heavy infestations. The nymphs do not crawl far from their hatching place. The principal mite population on a plant is found on the outer margins of the infested parts. In heavy infestations the mites literally crawl over one another and give the appearance of fine yellowish dust on the plant.

In the laboratory the mites have been reared on tomato and petunia leaves with successful transfers having been made. Observations of the mites' activities have to be made under at least a 20 diameter magnification. Many hours have been spent watching them but neither copulation nor actual egg laying has been observed. The size of the egg in comparison to the adult size indicates that considerable food must be ingested for the development of each ovum. The number of eggs laid by any one female russet mite was not counted above 15. However, Putman (1939) records a female *Phyllocoptes fockeui* on plum as having laid as many as 79 eggs.

Putman further states that unfertilized *Phyllocoptes fockeui* females lay eggs which hatch into males only, these males then fertilizing the female to produce female progeny. This arrhenotokous type of reproduction, which is exhibited by other types of mites and certain insects, is also the type possessed by *P. destructor*. While the writers did not investigate this in particular, in 5 rearing chambers unfertilized females which had been isolated as nymphs (nymphs have no external genitalia) showed the following production after becoming adult: (1) in 7 days 8 nymphs; (2) in 7 days, 5 nymphs and 1 egg; (3) in 7 days, 3 adults, 8 nymphs, 1 egg; (4) in 7 days, 2 adults, 8 nymphs, 2 eggs; (5) in 7 days, 4 adults, 5 nymphs, 4 eggs. Subtracting two days for the preoviposition period an average production of nearly two a day is indicated. Thus an unfertilized isolated female can found a new colony.

One culture of this mite which was started with one presumably mated adult female had the following results: in 5 days the female, 2 or more eggs, and 1 first nymph present; in 7 days the female, 3 eggs, and 10 nymphs; in 9 days 8 adults, 12 nymphs; in 10 days 12 adults, 12 nymphs, 4 eggs; in 11 days 29 individuals; in 12 days 20 adults, 11 nymphs, 16 eggs; in 13 days 43 individuals; in 14 days 71 individuals; in 16 days 106 individuals; in 20 days 51 eggs and 204 individuals; in 22 days 155 adults, 64 second nymphs, 36 first nymphs; a total of 255 individuals, and 53 eggs. After the first week the population in this case doubled every 3 or 4 days.

The shortest life cycle observed in the laboratory at about 70° F. was: preoviposition period 2 days; incubation 2 days; first nymph 1 day; second nymph 2 days; total length of time from adult to adult 7 days. Five separate cultures simultaneously gave this result. These were males from unfertilized eggs and we have no direct data on female growth. Mites exposed to the sun's heat probably have individual life cycles shorter than this.

Counts of the sex ratio were made by removing every adult from a unit of leaf area to a microscope slide. In two cases one-fourth inch square of upper surface was used. In one case, the mites were all removed from one-half of the upper surface of a leaf. In the fourth collection all adults were removed from a small leaf. The results are respectively: (1) 47 males, 35 females; (2) 89 males, 16 females; (3) 46 males, 60 females; (4) 124 males, 57 females. Total males 474 or 64 per cent; females 168 or 36 per cent.

Feeding is by means of a pair of needle-like chelicerae in a groove on the anterior side of the sucking beak or trunk. The chelicerae are apparently on a spring mechanism with extensor muscles only, as they tend to lift upward when the musculature is destroyed by the mounting medium. These chelicerae puncture the surface cells of the host but the killing action is probably due to the saliva produced by the mite.

The majority of surface-inhabiting Eriophyids are not only confined to the leaves of their host when feeding and breeding, but occur only on the under surface of the leaves. The russet mite, in contrast to this, feeds on all green surfaces and is able to resist direct sunlight with no apparent inconvenience. The peach silver mite and citrus rust mite are similar to the russet mite in respect to living in full sunlight.

The mites travel about an infested plant by crawling and can move about one-half inch in two minutes. They abandon the

injured drying parts for the fresh green surfaces. When there is no more fresh tissue, the mites crawl to the tips of stems, leaves, up hairs, etc. In these locations they rear up on their posterior abdominal lobes and claw the air, obviously waiting to grasp whatever comes along. They also drop from a dying plant, presumably having launched out after failing to obtain a carrier. In the early spring of 1942 two small tomato plants were planted on opposite sides of a ten-inch pot and the pot placed at a window. One plant was infested with russet mites. It soon began to decline but due to lack of sufficient air currents the mites did not reach the other plant until about four weeks later when the infested plant was nearly dead. This is good evidence that they may be wind blown or carried on tools, boxes, clothes, and by irrigation water. Some tomato fields have not been found infested until after the first picking.

SEASONAL CYCLE.—The tomato russet mite's yearly development does not include the ability to hibernate or the production of hibernating forms. Growth and survival of the species depend on perennial availability of green tissue. Thus reproduction is continuous as long as conditions permit, and really only slows down at minimum survival temperatures of the host plants. At such times the mites are sluggish and remain in leaf axils, stem crevices or curled leaves and the population is usually sparse. Greenhouse tomatoes are an excellent habitat for the species at any time of year. All stages, including eggs, may be found in midwinter on the leaves of protected outdoor nightshade plants in the Sacramento Valley (Elkhorn district, Yolo County, February, 1943).

Laboratory experiments with infested tomato leaves have shown that adults and second nymphs will survive a 10-day exposure to 34° F. constant temperature. Nearly all first stage nymphs were killed during this exposure but about half of the eggs survived. If the mites remain in this temperature, the second instar nymphs all die after about 21 days. At 22° F. constant temperature the mortality of the active stages on tomato leaves was as follows: 1 day, 53 per cent; 2 days, 94 per cent; 3 days, 99 per cent; 4 days, 100 per cent. Two days' exposure killed all the eggs and only a few quiescent mites in the process of molting survived the three-day exposure. We do not know the feeding requirements of the mite at minimum temperatures, but adults survived 4 days in the summer without food. When submerged in water total mortality occurs in about 12 hours.

In the valley area of central and northern California where we have had three seasons' experience with the species, the mites become completely separated during the winter from all outdoor tomatoes and exposed black nightshades. Black nightshade usually is frost killed to the ground but the root may remain perennially, which does not serve the mite. This separation is so complete that severely-infested tomato fields planted to sugar beets the following year have no mites present on nightshade in or about the fields. Petunia is superior to nightshade as a summer host for the mite and presumably also as a winter habitat. To serve thus, both plants must have suitable protection near buildings or in brush. Whatever the overwintering Solanaceous host happens to be, a very meagre survival of the mites can produce heavy infestations on their hosts by late summer.

Conditions on the immediate California coast, such as the San Francisco Bay region, and on down to southern California may be somewhat different from the above, but the russet mite is just reaching most of these locations. Where winter hosts, and even tomato, are not affected by frost, the mite will survive in greater numbers and may produce earlier damage in tomato fields.

Observations in the Sacramento Valley seem to show that the mites may infest young tomato plants in the cold frames, depending on their proximity to infested Solanaceae. At this time the mites are impossible to find on the small tomato plants because of their minute size and sparse population. The spotted, irregular manner in which first colonies can be found in tomato fields (about a month after planting) indicates that the initial infestations are largely a matter of chance. It is known definitely that groups of plants from individual plant beds are frequently more uniformly infested than

those from others. Consequently some fields or portions thereof receive a greater initial infestation than others. Some infestations have been observed to start on the lee side of lone oak trees indicating that a mite was dropped from the wind in the resulting eddy. During July the infestations spread rapidly within tomato fields and contributions from other Solanaceous plants are of minor concern. The peak of the seasonal population is reached in late September.

NATURAL ENEMIES.—The natural enemies of *Phyllocoptes destructor* appear to be few. The principal one observed to date is a predaceous Parasitid mite, possibly *Seiulus* sp. which feeds on all stages. In small gardens this mite keeps the tomato mite under control. Inoculations of home-grown tomato plants have failed in all cases because of the predaceous mites. In laboratory rearing experiments, individual tomato leaves had to be carefully examined under a microscope and the predaceous mites removed, before they could be used. Otherwise all cultures were destroyed. In commercial fields, however, the predaceous mite does not occur in sufficient numbers to prevent the breeding up of high populations. Another known enemy of the tomato mite is the predaceous thrips, *Leptothrips mali* (Fitch). This insect, as well as others, appears to dislike the tomato vine because of the viscous hairs on the plant which causes their appendages to become stuck together. Only once has this thrips been actually seen feeding on *P. destructor*. Occasionally a predaceous itonidid (Cecidomyiid) maggot has been seen among tomato russet mites. These maggots are known to feed on various Eriophyids. On petunias the predators appear to be even more scarce (particularly on the stems) than on the tomato.

CONTROL.—All types of insecticidal dusts have been tried in control studies. Various combinations of contact materials with sulfur all gave good control but when the sulfur was omitted, the results were unsatisfactory. Straight dusting sulfur (325 mesh) gave practically 100 per cent control with no burning of the plants. Sulfur has the advantage of low cost and is compatible with calcium arsenate necessary for use against various caterpillars commonly attacking tomatoes (Campbell 1942). For garden tomatoes and fruit sold to the fresh fruit market, it is difficult to improve on a light sulfur dusting applied to the plants about every four or five weeks.

On canning tomatoes, however, even a minute amount of sulfur remaining on the fruit which is not removed by washing, causes a reaction in the can resulting in an odor and flat taste of the pack. Preliminary tests in 1941 showed that a 25 per cent sulfur dust did not leave sufficient residue on the fruit to be objectionable (Bailey 1941).

During the past two seasons several thousand acres of commercially-dusted fields have been examined to determine the best type of deposit, time and number of applications, and amount per acre to produce the best practical control. A complete report on the results of the control experiments and canning tests will be published later. The conclusions based on northern California conditions are herewith summarized: In the Sacramento Valley no dusting is necessary before the middle of July. A good dusting, applying 30 pounds of a 25 per cent sulfur mixture (with or without a stomach poison) per acre, will hold the infestation down for 3 to 4 weeks only. A second dusting a month later, and particularly after the first picking, is usually necessary in early infested fields. Row-crop dusters (Fig. 3) give the most satisfactory application.

Dusting for the mite after the middle of September is generally not justified since most of the injury has been done; cooler weather slows down reproduction of the mite and lessens the danger from sunburning of the fruit.

Cultural control and plant bed management appear at present to play a very minor part in the control program. The placing of the plant beds in relation to petunias and nightshade-free areas should be considered but is often not practical. Dusting the plants with sulfur in the plant bed previous to setting them in the field may be of some value but would give little protection as the plant grows and possible wind-blown mites later infest the fields.[1]

[1] We wish to acknowledge the assistance of W. D. Norton, Ivor Burden, Ray Barron, H. A. Hunt, and particularly the generous help and constructive advice of Robert Rose in the control studies.

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Isoamyl Salicylate as an Attractant for Hornworm Moths[1]

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The tobacco hornworm, *Protoparce sexta* (Johan.), and the tomato hornworm, *P. quinquemaculata* (Haw.), attack tobacco wherever it is grown in the United States. The most serious damage is usually found in southern areas, but losses may be severe in Maryland and other more northern states. Partial control is obtained by applying lead arsenate or a mixture of paris green and lime, but both these dusts, especially lead arsenate, leave undesirable residues on the market product. Cryolite dust has proved to be moderately effective in some sections but in others it has not been satisfactory. The residue from cryolite is undesirable also.

Blossoms of the jimsonweed, *Datura stramonium* L., emit an odor which is very attractive to the adults of both species of hornworms attacking tobacco and, prior to the development of dusts and sprays for the control of the larvae on tobacco plants, the moths were partially controlled by means of poisoned syrup placed in newly opened blooms. This control method was moderately effective, but it necessitated placing poison in fresh blooms daily.

For several years tests have been conducted at Clarksville, Tenn., with many aromatic chemicals, some of which have been found to have odors attractive to the moths, and with artificial jimson blooms, for the visual attraction of the moths. Morgan & Lyon (1928) reported the early progress with attractants, and later Gilmore & Milam (1933) published the results of experiments with hornworm moth poisons and with imitation blossoms. Isoamyl salicylate, commonly used as a base for perfumes, is as effective as any chemical tested and is used in preference to others because it is easily obtained and is comparatively inexpensive. Moths are attracted from considerable distances by the odor of this chemical diffused from a small sack of fullers' earth or from a disk of plaster of paris impregnated with the material. The odor may be diffused, but less effectively, from a short length of lamp wick extending into a vial of isoamyl salicylate.

Visually, moths are attracted to a simulated cluster of jimson blooms consisting of three small white tin funnels inserted in the top of a slip-cover can painted green, the assembly being known as a feeder (Fig. 1). The feeder may be used to lure moths into a trap or it may be filled with a liquid bait containing 10 per cent of sugar combined with 5 per cent of tartar emetic or 0.04 per cent of rotenone from aqueous extract of derris or cube, either of which is toxic to the moths. The bait in the imitation blooms is taken freely by the moths at sunset and again at dawn, the periods of normal moth activity.

The most effective trap tested to date, to be designated as the short-funnel model (1942) (Fig. 1), consists of a wood frame 36 inches long, 24 inches wide, and 34 inches high, covered on top and sides with wire screening and equipped at each

[1] Paper prepared for the Program of the Cotton States Branch, 1943.

end with a screenwire entrance funnel extending inwardly about 10 inches. A hardware cloth baffle hung between the two funnels prevents moths from flying directly through the trap. The short-funnel trap differs only slightly from an earlier model known as the long-funnel trap (1941), described in United States Patent 2,257,655, issued to Scott & Milam in 1941. The long-funnel model is somewhat larger than the short-funnel trap and its entrance funnels are offset to the right so that moths can not fly directly through both funnels and thus escape.

It has been shown repeatedly that traps or poison feeders destroy sufficient numbers of moths to cause decided reductions in worm infestation, but there is no evidence that either of these control measures will provide satisfactory protection when moths are more than moderately abundant. In 1941 the results of a small-scale experiment in four fields of tobacco indicated that adequate protection can be obtained from traps or feeders in an area of light infestation. One field of 1.5 acres was protected by four traps, while another of 3 acres was protected by 10 feeders. The other two fields served as checks, receiving no treatment from those conducting the experiment. The owners were advised to apply whatever control measures they deemed necessary. No additional treatment was required in the protected fields, but the owner of one check found it necessary to hand-worm his tobacco each day during the experiment, while the owner of the other applied lead arsenate once and hand-wormed once. Weekly observations of 100 random plants in each of the four fields showed that worms and eggs were much more prevalent in the checks than in the protected fields. The infestation data are summarized in table 1.

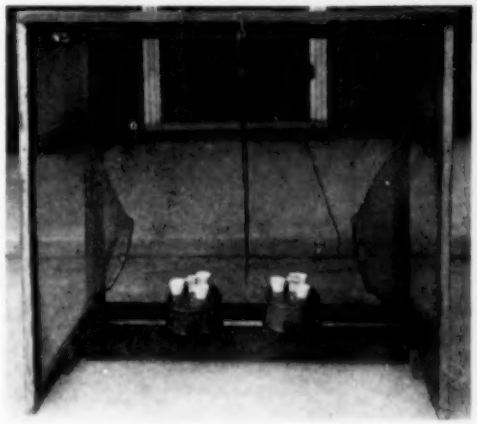

FIG. 1.—Side view of short-funnel hornworm moth trap with side toward camera removed to show feeders and vials of isoamyl salicylate in position.

In July and August the infestation was very low in the protected fields and the owners found it unnecessary to apply insecticides, but hornworms were moderately abundant in the checks and handworming or insecticides were necessary to avoid severe damage. Early in September there was an unusually heavy flight of moths which resulted in a decided increase in infestation in all four fields, and it would have been necessary to apply insecticides to the protected fields had they not been harvested. This indicated that traps or feeders offer adequate protection only when moth population is low.

The 1942 hornworm infestation in north-central Tennessee was one of the severest experienced by that area in many years, and the results of a large-scale control experiment indicated that neither traps nor feeders can be depended on to provide complete protection against hornworm larvae when moths are prevalent. The experiment was conducted in nine widely separated square-mile areas, 3 of

Table 1.—Comparative hornworm infestation in tobacco fields protected by moth traps or feeders and in unprotected fields, July 1, to September 10, 1941.

FIELD	ACRES	TREATMENT	OBSERVATIONS	PLANTS EXAMINED	EGGS FOUND	LARVAE FOUND	MOTHS TAKEN FROM TRAPS	OTHER TREATMENT
1	3.0	10 feeders	6	600	13	90	—	None
2	1.5	4 traps	5[1]	500	25	89	72	None
3	1.5	Check	6	600	39	330	—	Hand-wormed every day
4	2.1	Check	6	600	103	184	—	Two applications of lead arsenate.Hand-wormed once

[1] Crop harvested prior to sixth observation.

which were protected by traps, 3 by poison feeders, and 3 were unprotected. These treatments were assigned to the 9 areas by the randomized-block method. Twenty-four traps were placed in each of three areas of one square mile, whereas 48 poison feeders were placed in each of three others, the remaining three areas serving as checks and receiving no experimental treatment. Of 24 traps placed in an area, 12 were of the short-funnel type, the remainder of the long-funnel type. Each trap was equipped with two feeders which served to attract moths visually. The feeders in six traps of each type were equipped with small lamp wicks inserted in 1-inch vials of isoamyl salicylate, which diffused the odor of the attractant, and the feeders of the remaining six were equipped with disks of plaster of paris 5.5 inches in diameter and 1.25 inches thick impregnated with isoamyl salicylate.

Table 2.—Comparative effectiveness of two types of hornworm moth trap and two means of diffusing the odor of the attractant, isoamyl salicylate, to which moths are attracted.

Type of Trap	Means of Diffusing Odor of Attractant	Total Moths		
		Male	Female	Total
Short-funnel	Vial-wick	1103	1288	2381
Short-funnel	Plaster of paris disk	1590	1647	3037
Long-funnel	Vial-wick	708	869	1577
Long-funnel	Plaster of paris disk	1744	2156	3900
	Totals	4945	5950	10895

Forty-eight poison feeders were placed in each of 3 1-square-mile areas, each feeder being equipped with a plaster of paris disk for diffusing the odor of the attractant and each filled with liquid bait containing 10 per cent of sugar, 0.04 per cent of rotenone from aqueous extract of derris, and 0.5 per cent of sodium benzoate as a preservative. Every 14 days the bait was renewed and isoamyl salicylate added to vials and plaster disks.

The relative effectiveness of the treatments was estimated by means of weekly infestation observations of 100 random tobacco plants in a random field in each square-mile area, 20 plants being taken from the center of each quarter of the field and 20 from the center of the field. Records were made of the numbers of eggs and larvae found, and at the same time information was obtained from the grower concerning control measures applied by him.

Moths recovered from the traps totalled 10,895, of which 5950 were females. In addition to the moths recovered, many dropped to the ground and were washed away by surface water, while others were destroyed by birds, skunks, snakes, or farm animals. The recoveries are summarized in table 2.

Prior to 1942 the short-funnel trap was believed to be more effective than the long-funnel model, but in all the early tests the odor of the attractant was diffused from small wicks in 1-inch vials. The results of the tests in 1942 show that, for the conditions under which this particular experiment was conducted, the short-funnel trap was more effective when both models were equipped with vials and wicks and that the reverse was true when both models were equipped with plaster of paris disks impregnated with isoamyl salicylate. The plaster disks were definitely more effective than the vial-wick combination.

Approximately three times as many eggs were deposited in the check areas as in the areas protected by traps or poison feeders—indicating that both treatments were effective in destroying moths. The larval recoveries, however, were only twice as great in the check areas as in the protected areas. There was a tendency for farmers in the protected areas to depend on the traps or feeders for control and therefore to make fewer and smaller applications of insecticide. The infestation data are summarized in table 3.

Table 3.—The infestation of tobacco with hornworm eggs and larvae as affected by the use of traps and poisoned bait in 1-square-mile areas to catch or poison the moths.

	Eggs on 700 Plants in Each Indicated Area				Larvae on 700 Plants in Each Indicated Area			
	1	2	3	All	1	2	3	All
Traps	177	217	63	457	272	351	226	849
Poisoned baits	130	192	90	412	307	440	174	921
Check	348	775	98	1221	735	772	265	1772

The farmers applied lead arsenate an average of 2.33 times in the check areas, 1.66 times in the trapped areas, and 1.55 times in the baited areas. In general, the rate of application was less in the areas protected by poison feeders or traps than in the unprotected areas because farmers make light applications when infestation

is light or moderate and comparatively heavy applications when larvae are plentiful.

The results of the experiment indicate that there was practically no difference in the effectiveness of the two treatments. The results from the traps were more spectacular than those from the feeders because it was not unusual to find a hundred or more moths in a single trap after it had been in operation for a week, whereas the moths killed by poison usually died at a considerable distance from feeders and were not found. Traps, however, are more expensive than feeders, are more difficult to transport, and require more space for storage. They are more susceptible to damage by weather and farm animals and are attractive targets for small boys, but they provide valuable information concerning the most favorable locations for trapping or poisoning moths. Moths may be poisoned or captured in greatest numbers if the trap or feeder is placed immediately adjacent to growing tobacco. A slight elevation is preferable, especially if there is a valley or draw leading to plantings of tobacco. A sloping field can be protected most effectively if a majority of the feeders or traps are placed on the elevated side, permitting the odor of the attractant to spread by gravity to and beyond the planting.

It is suggested that plantings of less than an acre be protected by at least two traps or feeders and that larger plantings be protected by at least two per acre. In unusually large fields some of the feeders or traps may be placed inside the planted area but it is generally advisable to place them on the border sufficiently removed from the planting to permit cultivation. Rotenone bait is preferable to one containing tartar emetic because the former is less toxic to humans and livestock.

SUMMARY.—The adults of two species of hornworms, *Protoparce sexta* (Johan.) and *P. quinquemaculata* (Haw.), which attack tobacco are attracted from a considerable distance by the odor of the blossoms of jimsonweed, *Datura stramonium* L., and by the odor of isoamyl salicylate, the latter diffused from a small sack of fullers' earth, a plaster of paris disk, or a short length of lamp wick. The moths are attracted visually by a simulated cluster of jimsonweed blooms consisting of three small white tin funnels inserted in the top of a 5.5-inch slip-cover can painted green, the assembly being known as a poison feeder. A sweetened liquid bait containing 0.04 per cent of rotenone (from aqueous extract of derris or cube) or 5 per cent of tartar emetic is taken readily by the moths and is moderately toxic to them. Moths attracted by isoamyl salicylate may be poisoned or trapped in large numbers. The most effective trap consists of a wood frame covered with wire screening and equipped with two inwardly projecting entrance funnels. The results of tests conducted in 1941 and 1942 indicate that hornworm infestations can be materially reduced by moth traps or by poison feeders and that either of these methods is of value as a supplementary control.—5-21-43.

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★ ★ LIEUTENANT ELMO F. MCCLAIN ★ ★

Dr. Z. P. Metcalf reports that Lieutenant Elmo F. McClain, a graduate of Mississippi State College, where he took major work in Entomology and, later, a graduate student in Entomology at the North Carolina State College, has been reported missing in action over Sicily.

Insecticide Tests for Boll Weevil and Cotton Aphid Control in the Mississippi Delta

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The boll weevil, *Anthonomus grandis* Boh., and the cotton aphid, *Aphis gossypii* Glov., are the two principal cotton-insect problems in the Delta section of Mississippi. In order to obtain more information on the control of these two insects, calcium arsenate and a 1:2 calcium arsenate-sulfur mixture, with and without aphicides, were tested at Stoneville and Scott, Miss., in 1942.

Methods and Materials.—Two series of tests were conducted and are referred to as large- and small-plot tests. Single-nozzle, 1-row rotary hand guns were used for applying the insecticides in the small plots, but power and power take-off row dusters were used in the large plots, except for one application made with hand guns in part of the tests. In all tests the treatments were applied in the morning, usually early, when the air was generally fairly calm and the cotton was for the most part moist or wet with dew. The applications were made as nearly as possible at 4- to 5-day intervals when the boll weevil infestation exceeded 15 to 25 per cent in the treatment showing the best control. Some of the late applications, however, were made for protection of the young bolls.

The infestation records for the boll weevil were made by examining 300 squares for feeding and egg punctures in each of the large plots, and 200 squares per plot in the small plots. Infestation records for the aphids consisted of counting the aphids per square inch on 300 square inches of leaf area in each of the large plots, and on 100 square inches per plot in the small plots. The under side of the fourth leaf from the top of the plant was used for making the counts. The records for both insects were made at about weekly intervals.

Yield records were made from 0.2, 0.1, or 0.053 acre in the large plots. In the small plots the yields were from 0.05 acre, except for two plots where 0.025 acre was used.

The calcium arsenate and sulfur used were commercial products and the nicotine was from nicotine sulfate. The rotenone used was from cube containing 4.1 per cent of rotenone and 18.3 per cent of total extractives, as determined by the Division of Insecticide Investigations, of the Bureau of Entomology and Plant Quarantine. The 1:2 calcium arsenate-sulfur mixtures with aphicides were commercially prepared and the active ingredients shown for the latter were those given by the manufacturer. About 5 per cent of hydrated lime was added to the mixtures containing nicotine, in order to insure liberation of the latter.

Large-Plot Tests.—The large-plot tests were cooperative, with the growers furnishing most of the insecticides, the labor, and the equipment for applying the materials, and members of the laboratory force supervising the applications and making the records. There were three replications of each treatment, one in each of fields 1 and 2 at Scott and one in field 3 at Stoneville. In size the treated plots ranged from 1.9 to 3.6 acres and the untreated plots from 0.8 to 1.4 acres. At the time the dusting operations were begun the boll weevil infestation in the three fields averaged 15.6 per cent in the treated plots and 21.2 per cent in the check plots. Six applications of insecticides were made in fields 1 and 2 and four applications in field 3, between July 14 and August 17. All applications were considered effective, as there was not sufficient rain within 24 hours to require redusting. The materials were not weighed, but an attempt was made to apply each at the rate of 6 to 8 pounds per acre, depending on the size of the cotton. Through error, one late-season application of calcium arsenate was made by airplane to all plots of field 2, but this was thought to have had but little, if any, effect on the final results, as the dust was washed off by rain in about 12 hours. Three boll weevil infestation records were

[1] In the armed forces.

[2] In cooperation with the Mississippi State Experiment Station and the Mississippi State Plant Board. Thanks are extended to M. S. Henry and to J. F. Ellard for assistance in making the field notes and to J. C. Gaines for making the statistical analysis.

made in field 1, 4 in field 2, and 1 in field 3 after dusting had begun. During the same period five aphid population records were made in fields 1 and 2, and three records in field 3. The treatments and results are summarized in table 1.

Small-Plot Tests.—The small plots were all located at Stoneville and contained 0.2 acre each. They were arranged in randomized blocks with four replications of each treatment, two in each of two fields on the same farm. Four applications of each insecticide were made between July 27 and August 13, all of which were effective. The average dosage of the calcium arsenate, alone and with aphicides, ranged from 7.3 to 8.8 pounds per acre per application, while the 1:2 calcium arsenate-sulfur mixture, with and without aphicides, ranged from 12.8 to 13.4 pounds. As the tests were started late in the season, only one infestation record was made for the boll weevil after dusting had begun. Four aphid-population records, however, were made after the initial dust application. The treatments and results are shown in table 1.

Discussion.—Treatments of calcium arsenate and calcium arsenate plus 2 per cent of nicotine in alternate applications, and calcium arsenate plus 1 per cent of nicotine in all applications, gave satisfactory control of the boll weevil and aphids in both large- and small-plot tests. The increase in yield over the check for alternate applications of calcium arsenate and calcium arsenate plus 2 per cent of nicotine was 415 pounds of seed cotton per acre in the large plots and 323 pounds in the small plots, whereas the increase for the calcium arsenate plus 1 per cent of nicotine in all applications was 394 and 318 pounds, respectively. Following the use of calcium arsenate without an aphicide there was a loss of 138 pounds per acre in the large plots and a gain of 11 pounds in the small plots. The average difference in yield between the two calcium arsenate-nicotine treatments and the calcium arsenate alone of 542 pounds in the large plots and 310 pounds in the small plots seemed to be due largely to aphid damage.

In the small-plot tests better boll weevil

Table 1.—Boll weevil and cotton aphid infestations, and yields of cotton, following different insecticidal treatments.

Treatment	Squares Punctured by Boll Weevil	Aphids per Square Inch of Leaf Area		Yield of Cotton per Acre	
		Maximum	Average	Total	Gain
	Per Cent	*Number*	*Number*	*Pounds*	*Pounds*
Large-plot tests, three replicates:					
Check	38.6	10.41	4.94	2132	
Calcium arsenate plus 1% nicotine[1]	21.2	6.59	3.24	2526	394
Alternate applications of calcium arsenate and calcium arsenate plus 2% nicotine	9.8	7.12	4.66	2547	415
Calcium arsenate	15.8	39.95	17.99	1994	−138
Small-plot tests, four replicates:					
Check	50.0	13.75	7.22	1912	
Calcium arsenate plus 1% nicotine	8.1	16.25	8.32	2230	318
Alternate applications of calcium arsenate and calcium arsenate plus 2% nicotine	14.3	12.31	6.55	2235	323
Calcium arsenate plus 0.5% rotenone	10.5	20.92	10.82	2012	100
Calcium arsenate and sulfur 1:2, plus 1% *Lethane 60*[2] and 0.5% nicotine	27.4	11.47	6.39	2160	248
Alternate application of calcium arsenate and sulfur 1:2 and calcium arsenate and sulfur 1:2 plus 1% *Lethane 60* and 1% nicotine	24.5	14.05	8.01	2174	262
Calcium arsenate and sulfur 1:2	25.1	26.99	13.39	1997	85
Calcium arsenate	12.5	34.00	18.19	1923	11
Minimum significant difference at 5% level	12.1		1.76	200	

[1] All nicotine from nicotine sulfate.
[2] An insecticide concentrate containing not less than 50 per cent, by volume, of beta-thiocyano ethyl esters of fatty acids whose average carbon content is from 10 to 18.

control was obtained in all treatments with calcium arsenate than with the 1:2 calcium arsenate-sulfur mixture, but without aphicides the calcium arsenate caused significantly more aphids to develop than did the mixture. The average difference in yield of 170 pounds per acre between treatments with the calcium arsenate-sulfur mixture plus aphicides and the mixture alone is attributed largely to aphid damage, as the boll weevil infestation was about equal for all treatments.

Treatments of calcium arsenate plus nicotine and the calcium arsenate-sulfur mixture plus nicotine and *Lethane* 60 all gave significantly better aphid control than calcium arsenate plus 0.5 per cent of rotenone. These tests indicate that the losses in yield due to the increase in aphids following the dusting of high-yielding cotton with calcium arsenate may exceed the gains obtained from control of light to moderate boll weevil infestations.—5-25-43.

Substitutes for Rotenone in Cattle Louse Control[1,2]

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Cattle lice are a serious problem in the winter and early spring months in dairy herds in the northeastern United States. All four species of cattle lice are present in New York. The cattle biting louse (little red louse), *Bovicola bovis* (L.) (Mallophaga) is the most common and most serious pest. The long nosed blue louse, *Linognathus vituli* (Linn.) (Anoplura) is the commonest and most serious sucking louse. The little blue louse, *Solenopotes capillatus*, Enderlein (Anoplura) is found somewhat sporadically, but is sometimes a serious pest. The short nosed cattle louse, *Haematopinus eurysternus* (Nitzsch) (Anoplura) is not a very serious pest of dairy cattle in New York State, but it is serious on beef stock. In the vicinity of Ithaca in central New York it was difficult to find infestations of *H. eurysternus* on dairy cattle to use for dusting experiments. The various materials used were tested against all four species of lice.

Since it is impractical to dip or spray to control these pests on dairy cattle under New York conditions, dusting is the usual treatment.

During the winter of 1941–42, 211 cattle in 12 herds were dusted with rotenone and sulfur at various concentrations. It was established that a mixture of 1 part cube (5 per cent rotenone) to 10 parts wettable sulfur gave very good control of all species of cattle lice. During the winter of 1942–43, 304 cattle in 13 herds were dusted with a number of insecticides of supposed value as substitutes for rotenone. These included nicotine (*Black Leaf 10* and *Black Leaf 155*), pyrethrum (*Stimtox A*), sabadilla, hellebore, *Lethane* (beta-thiocyano ethyl esters of fatty acids), *Thanite* (secondary terpene alcohol thiocyanate), *Velsicol* (isomeric mixture of alkyl substituted naphthalenes), and ground yam bean (Hansberry & Lee, 1943).

The dusts were applied with a knapsack type puff duster. A special wide nozzle was fashioned from sheet iron, to which flaps of canvas were attached to help confine the dust (Figs. 1 & 2). In all cases only a single application was made. The usual dose was 3 to 4 oz. per animal. This of course varied with the size of the animal. The diluent used in most cases was wettable sulfur. It was found early in the work that a heavy application of sulfur alone gave fairly good control of the biting louse, *Bovicola bovis*, but not of the sucking lice. No difference was found in the toxicity of wettable and dusting sulfur, but the wettable stayed in the hair coat better and gave less dust fog in the barn.

In the table the mortality percentages are rounded weighted averages of a series of tests. The counts were taken by removing lice and hair from treated animals and examining immediately in the laboratory. The true kills are higher because some dead lice fall from the hosts. Never-

[1] This is a report on an investigation carried on by the Department of Entomology, of the New York State College of Agriculture under a fellowship provided by the Agricultural Department of the Texas Gulf Sulfur Company, Houston, Texas.
[2] Early publication accorded this paper because of payment of printing costs by the authors.

theless, these figures are a good basis for comparison of toxicity of the insecticides used.

As can be seen from the table, pyrethrum, nicotine, and hellebore were of little value in the control of lice. Even *Black Leaf 10*, which is high in free nicotine, gave poor control. Hellebore has often been recommended for cattle louse control but it is apparently ineffective. Pyrethrum was tested on 14 animals but in no case was it of much value.

FIG. 1.—Knapsack type puff duster with broad nozzle for dusting cattle.

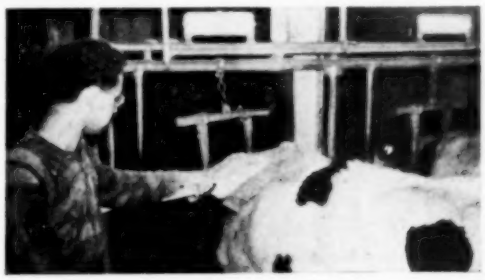

FIG. 2.—Dusting a heifer for cattle louse control.

Dusts containing *Thanite* and *Lethane*, reduced louse infestations but did not clean them up. *Solenopotes capillatus* was particularly resistant to these insecticides. The control of cattle lice by *Thanite* and *Lethane* was somewhat erratic; in most cases all lice except *S. capillatus* were fairly well controlled, but in a few instances the control was poor.

Velsicol gave poor kills within a week's time, but fairly good control over an extended period. More work with this material is necessary before any conclusions can be drawn.

The three materials that gave consistently good control of all species were rotenone, sabadilla, and yam bean. In all cases these materials at 1 to 10 concentration with wettable sulfur yielded high kills of lice within a week, and no reinfestation occurred over an extended period. Sabadilla was effective even at 1 to 20 concentration. Sabadilla at 1 to 10 and 1 to 20 concentration gave practically perfect control of all species except *S. capillatus*, and at 1 to 10 gave good control of this species also. Yam bean was somewhat slower acting than sabadilla and rotenone, but nevertheless yielded very good control. Either of these materials could substitute for rotenone. Sabadilla should be ground finely before diluting with sulfur. As commonly purchased it is too coarse for maximum effectiveness.

Table 1.—Toxicity of Dusts to Cattle Lice, New York 1941-1943.

DUST	INFESTATION	MORTALITY IN 7 DAYS (PER CENT)	HERD CONDITION IN 3 WEEKS
Cube Sulfur, 1–10	*B. bovis*	100	Clean
	L. vituli	100	Clean
	H. eurysternus	100	Clean
	S. capillatus	100	Clean
Cube Sulfur, 1–16	*B. bovis*	100	Clean
	L. vituli	100	Clean
	H. eurysternus	100	Clean
	S. capillatus	75	Infested
Pyrethrum (*Stimtox A*) Sulfur, 1–10	*B. bovis*	80	Very light infestation
	L. vituli	20	Infested
Nicotine (*Black Leaf 155*) Sulfur, 1–10	*B. bovis*	90	Very light infestation
Nicotine (*Black Leaf 10*) Sulfur, 1–10	*B. bovis*	70	Very light infestation
	L. vituli	30	Infested
Thanite, 1 part *Celite*, 2 parts Sulfur, 8 parts	*B. bovis*	95	Clean
	L. vituli	85	Very light infestation
	H. eurysternus	95	Very light infestation
	S. capillatus	60	Infested
Lethane 60, 1 part *Celite*, 2 parts Sulfur, 8 parts	*B. bovis*	90	Clean
	L. vituli	80	Very light infestation
	H. eurysternus	80	Infested
	S. capillatus	60	Infested
Velsicol, 1 part *Celite*, 2.5 parts Sulfur, 7.5 parts	*B. bovis*	85	Clean
	L. vituli	20	Clean
Hellebore Sulfur, 1–10	*B. bovis*	20	Very light infestation
	L. vituli	10	Very light infestation
	S. capillatus	30	Infested
Sabadilla Sulfur, 1–10	*B. bovis*	100	Clean
	L. vitulli	100	Clean
	H. eurysternus	100	Clean
	S. capillatus	95	Very light infestation
Sabadilla Sulfur, 1–20	*B. bovis*	100	Clean
	L. vituli	100	Clean
	S. capillatis	90	Very light infestation
Yam bean Sulfur, 1–10	*B. bovis*	100	Clean
	L. vituli	100	Clean
	S. capillatus	90	Clean

To test further the toxicity of all the insecticides examined laboratory toxicity tests were conducted using *Bovicola bovis*. Cattle hair was placed in small (3 cm. diameter) dishes and dusted in a settling tower. Uniform deposits of .001 to .002 grams were obtained, then 10 or 15 adult female *B. bovis* recently removed from their host were placed in the dishes and kept at 90° F. Counts were taken twice a day for 5 days. The results agreed favorably with the field results. Rotenone was the most toxic material, with sabadilla second in toxicity. *Lethane*, *Thanite*, hellebore, pyrethrum and yam bean were all lower in toxicity. Nicotine was very poor, only slightly better than sulfur. The case of yam bean is the only one in which this test and field results disagree. It may be that yam bean is a slow acting insecticide, so that its effectiveness would not be apparent in the laboratory test.

SUMMARY.—Dusting is the common method of controlling lice on dairy cattle in the northern states. Rotenone is very effective for this purpose; a dust composed of 1 part cube or derris (5 per cent rotenone) to 10 parts wettable sulfur gives very good control of all four species of cattle lice.

Since the war seriously reduced rotenone supplies, substitutes were sought. The best dust found is composed of 1 part finely ground sabadilla seed to 10 parts wettable sulfur. This can be relied on to control all species of cattle lice. Ground yam bean seed, 1 part to 10 parts wettable sulfur, is also very effective. *Thanite* and *Lethane*, at 1 part to 10 parts of carrier, reduce infestations but cannot be relied on for good control. Nicotine, hellebore, and pyrethrum are ineffective under the conditions and concentrations of these experiments.—9-17-43.

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Agricultural Insecticides and Critical War Materials

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The war has caused a shortage of most of the metals and chemicals which are used to manufacture insecticides and fungicides. The War Production Board Conservation Division in its "Material Substitutions and Supply List," Issue No. 8, April 15, 1943, listed materials useful to the war program in three groups, ranked on the adequacy of existing supplies.

MATERIALS IN GROUP I.—In Group I (materials the available supply of which is insufficient either for war demands alone or for war plus essential civilian demands) are included (1) the inorganic materials arsenic and derivatives, copper and copper chemicals, tin, ammonia and derivatives, and chlorates; and (2) the organic materials pyrethrum, rotenone, benzene (benzol) and derivatives, phenol and derivatives, cresols, acrylonitrile, dichloroethyl ether, ethylene dichloride, formaldehyde, cashew nut shell oil, castor oil, coconut oil, mannitol, and sorbitol. All these materials are used directly or indirectly for the control of injurious insects, fungi, bacteria, or weeds.

Arsenic trioxide, known as white arsenic, is the starting material for the manufacture of all arsenicals. It is estimated that 30,666 short tons of white arsenic were consumed in 1941 in making the following insecticides:

ARSENICAL	WHITE ARSENIC CONSUMED IN TONS	PRODUCTION IN POUNDS
Calcium arsenate	13,595	75,208,856
Lead arsenate	8,960	62,885,021
Paris green	1,137	4,000,000
London purple	244	1,350,000
Sodium arsenite (as As_2O_3)	6,730	13,460,000
Total	30,666	156,903,877

The principal use of calcium arsenate (about 73 per cent) is for dusting cotton to combat the boll weevil and other insects. Large quantities are also used on potatoes (13.3 per cent) and on tomatoes (9.9 per cent). Other crops require only negligible quantities of this arsenical.

Lead arsenate is used primarily as a spray on fruit and shade trees. Apples require 55.7 per cent of the output, peaches and pears each 4.8 per cent, grapes 2.4 per cent, and shade trees and nurseries each 3.2 per cent. The Federal and State Governments, in control programs designed to hold the Japanese beetle, the gypsy moth, and other insects in check, consume 4 million pounds of lead arsenate, or 6.4 per cent of the total.

Paris green is used mostly on cotton (one-half the production), home gardens, potatoes, and tobacco. A highly important use of paris green is to combat the larvae of malaria-carrying mosquitoes.

London purple, which is a mixture of calcium arsenate and calcium arsenite, is used on cotton (1 million pounds) and on home gardens (350,000 pounds).

Sodium arsenite has been used extensively as a weed killer and for poisoning grasshopper bait. Sodium fluosilicate is a satisfactory substitute for sodium arsenite in grasshopper bait, but of the other materials that can be used to destroy weeds only a few are now available. Sodium chlorate, ammonium sulfamate, and ammonium thiocyanate are restricted.

Copper, which is one of the most critical materials, is indispensable for use in fungicides. It is the active ingredient of bordeaux mixture, and is also used for this purpose in the form of cuprous oxide, basic carbonate, oxychloride, phosphate, silicate, sulfate monohydrate, oleate, and naphthenate. Paris green and basic copper arsenate are other insecticides containing copper.

Specialists in the United States Department of Agriculture have listed the crops on which copper compounds must be used for the control of plant diseases in the order of their importance with respect to war value and need for copper treatment. It has been estimated that a total of about 20.4 million pounds of metallic copper were used during 1942. The most important uses on growing crops are nearly 9 million pounds for the control of early and late blight on potato in the Eastern, Southern, and Central States; and 5 million pounds for the control of scab blotch and bitter rot on apple in the South. Copper fungicides are used also on tomato, citrus in Florida, peach in California, grape, celery, and many other crops. For seed treatment about 1.25 million pounds of copper are required annually in the form of the basic carbonate and oxides. The 4 million pounds of paris green consumed annually require 1 million pounds of copper for its manufacture.

Tin is of interest to entomologists and others because tin cans are the only containers found suitable for nicotine sulfate solutions in 5- and 10-pound packages.

Ammonia is used with casein to emulsify spray oils in the Pacific Coast States. Ammonium sulfamate and ammonium thiocyanate are good weed killers.

The supply of pyrethrum available for the control of agricultural pests has become so critical that, effective May 1, 1943 (Food Production Order No. 11 of the War Food Administrator), its agricultural uses are restricted to the control of caterpillars on cole crops, including cabbage; leafhoppers and plant bugs on sugar- and other beet-seed crops; corn earworms on seed and sweet corn; leafhoppers on beans, potatoes, and raisin grapes; and worms and leafhoppers on cranberries. The use of pyrethrum is also permitted for the control of pests on vegetables grown in home, farm, community, and victory gardens; for the protection of cattle; and in dairy barns, dairies, creameries, cheese factories, and related establishments handling dairy products.

The use of rotenone insecticide is restricted by the War Production Board's Conservation Order No. M-133, as amended January 23, 1943, to the following uses:

1. Peas—protection against the pea weevil and pea aphid.
2. Beans—protection against the Mexican bean beetle.
3. Cole crops—other than cabbage, including broccoli, brussels sprouts, cauliflower, kohlrabi, mustard, kale, turnips, and collards—for protection against caterpillars and aphids.
4. Sweet corn—for protection against the European corn borer.

5. Cattle—for the specific control of the cattle grub (ox warble) or short-nosed cattle louse.

Benzene is an ingredient of the screwworm remedy called Smear No. 62, which was developed by the Bureau of Entomology and Plant Quarantine (Melvin *et al.* 1941). Of the benzene derivatives paradichlorobenzene is the most generally used. About 5 million pounds are consumed annually to combat the peachtree borer, and an equal quantity to combat clothes moths. Orthodichlorobenzene is used against termites, both alone and as a solvent for other synthetics.

Cresols and phenol are used in making disinfectants for livestock railway cars and chicken houses. Crude carbolic acid (phenol) has some use in bedbug sprays. Certain derivatives of these phenolic compounds—for example, 4,6-dinitro-o-cresol and 4,6-dinitro-o-cyclohexylphenol—are used as insecticides. Many phenoxy compounds have been patented for use in fly sprays, most of which are not effective in themselves but rather are intended partially to replace pyrethrum and to be used with it. These compounds have not yet come into commercial use.

Acrylonitrile has given promising results against the confused flour beetle, the rice weevil, and the bedbug, and appears worth further study as a fumigant (Richardson & Casanges 1942; Cotton & Young 1943).

Dichloroethyl ether has given promising results in controlling the corn earworm on corn, and wireworms, the sod webworm, and the plum curculio in soil. The amount consumed for these purposes remains small.

Ethylene dichloride is used to the extent of 6 million pounds annually as a grain fumigant. It is especially valuable for this purpose because it is cheap, is nontoxic to man, leaves no objectionable odor on grain, is toxic to many species of insects, and when mixed with one-third its volume of carbon tetrachloride has little fire or explosion hazard. Lately ethylene dichloride has come into use for combating the peachtree borer and for fumigating soil to kill Japanese beetle larvae.

About 756,000 pounds of formalin (containing 40 per cent of formaldehyde) were consumed in the United States in 1941 for disinfecting chicken hatcheries and for treating potatoes, oats, and other grains prior to planting.

Castor oil when sulfated makes Turkey-red oil, a valuable wetting and emulsifying agent which is suitable for use with derris. On destructive distillation castor oil yields undecylenic acid, the isobutylamide of which is an effective synergist for pyrethrum.

Cashew nut oil is of interest because a proprietary condensation product made from it has been used for increasing the solubility of rotenone and derris resins in petroleum spray oils for use against the California red scale.

Coconut oil yields lauric acid, which is used to esterify a mixture of mannitol and sorbitol to produce a proprietary wetting agent especially adapted for use with pyrethrum and derris extracts.

MATERIALS IN GROUP II.—Of the materials classified by the War Production Board as Group II (materials that are essential to the war industries but the supplies of which at present are sufficient to meet war demands plus only essential civilian demands), only mercury and mercury chemicals, certain chlorinated hydrocarbon solvents, diphenylamine, lauryl alcohol, naphthalene and derivatives, halogenated hydrocarbon refrigerants, cryolite, molasses, and certain oils such as sesame, fish, and pine are of much interest as insecticides.

Mercury is used in the form of calomel and corrosive sublimate against the cabbage maggot, as corrosive sublimate against the gladiolus thrips in corms of this plant, and in the form of ethyl mercuric chloride and other organic mercurials against fungi on seeds of corn, other cereals, and cotton. The annual consumption of organic mercurial seed disinfectants amounts to the equivalent of 85,000 pounds of metallic mercury.

Of the chlorinated hydrocarbons other than ethylene dichloride (which is in Group I), only carbon tetrachloride (6 million pounds annually) has extensive use as a grain fumigant. Carbon tetrachloride, which itself has low toxicity, is used in admixture with carbon disulfide and other fumigants to reduce their fire hazard.

Dichlorodifluoromethane (*Freon*), one of the refrigerants included in this group, is used to dissolve pyrethrum extract and sesame oil. The solution, which exerts a

pressure of 82 pounds per square inch at 68° F. and must be kept in a cylinder, is discharged into the atmosphere, leaving the insecticide suspended in the air as an aerosol. Such an aerosol is nontoxic to man and animals, noninflammable, and easily applied without the use of heat or power (Goodhue & Sullivan 1942). As little as 5 mg. of pyrethrins plus 10 mg. of sesame oil, which acts as a synergist, will kill all yellow fever mosquitoes in 1,000 cubic feet. This aerosol is especially well adapted to the fumigation of airplanes while in flight (Goodhue 1942).

Although cryolite is listed in Group II, recent information indicates that as much as 9 million pounds will be available for use as an insecticide in 1943. In 1941 the consumption for this purpose was nearly 5.4 million pounds. Both natural cryolite, all of which is imported from Greenland, and the synthetic product, which is a by-product of the aluminum industry, are suitable for insecticidal use. Cryolite is used against the orange tortrix in California, and is an acceptable substitute for lead arsenate against the codling moth in the Pacific Northwest and for arsenicals against the bollworm on cotton. It is also used on legumes and other tender plants against the white-fringed beetle. Additional testing by entomologists will doubtless find new uses for cryolite, which even now appears to be one of our most promising nonarsenical insecticides among the inorganic materials.

Diphenylamine, combined with benzene, is present in Smear No. 62, previously mentioned as a remedy for screwworm infestations of livestock. Diphenylamine is of further interest because when it is heated with sulfur and a catalyst phenothiazine is formed. Phenothiazine has given promising results against many species of insects in experimental trials and has proved highly efficacious in killing worms in swine, sheep, and other domestic animals. It is estimated that 2 million pounds will be consumed as an anthelmintic in 1943. It has several serious practical disadvantages, however, which may interfere with its commercial use as a spray.

Naphthalene is familiar to everyone as the material of which moth balls are made. The consumption for insecticidal use in 1941 was estimated to be 16.5 million pounds. Naphthalene is also effective as a soil fumigant against wireworms. Of the naphthalene derivatives only beta-naphthol is of interest to entomologists. Corrugated-paper bands impregnated with this compound and placed around trunks of apple trees kill codling moth larvae that crawl into them.

Lauryl alcohol is used in making a proprietary organic thiocyanate insecticide. Sodium lauryl sulfate, under various proprietary names, has been used as a wetting agent with derris and other insecticides. Lauryl alcohol is produced by reduction of lauric acid, which is derived from coconut oil.

Molasses is used with calcium arsenate for combating the boll weevil in the southeastern states. A mixture of 1 pound of calcium arsenate, 1 gallon of water, and 1 gallon of molasses is daubed on the plants with a homemade rag mop when the cotton begins to square. Molasses is also used in cutworm baits.

Sesame oil, mentioned above as a synergist for the pyrethrins, owes this property to its content of sesamin. Sesame oil can be used in a kerosene solution of pyrethrum extract as well as in freon.

Fish-oil soap has valuable emulsifying properties, especially when mixed with rosin soap, and is an ingredient of arsenical cattle dips.

Pine oil has been employed as an ingredient of fly sprays for use on cattle, and is used in making the widely known pine-oil disinfectant. Derivatives of terpene alcohols from pine oil are now marketed as activators and insecticides.

MATERIALS IN GROUP III.—In Group III the War Production Board lists those materials which are available in quantities significant enough to permit their use as substitutes for scarcer materials unless supplies are restricted locally by labor, manufacturing, or transportation difficulties. In this group are included antimony, lead and lead chemicals, nicotine sulfate, sulfur, sodium fluosilicate (sodium silicofluoride), methyl bromide, bentonite, lime, and pyrophyllite.

Tartar emetic, which contains 36.5 per cent of antimony, has been used successfully for about 6 years in California as a remedy for the citrus thrips. Recent work by Boyce *et al.* (1942) has shown that the citrus thrips in certain lemon groves in the San Fernando Valley is resistant to this compound. It is estimated that 100,000

pounds of tartar emetic were used for this purpose in 1942.

The abundance of lead is offset by the scarcity of arsenic, and the availability of lead arsenate will be determined by the supply of arsenic and not that of lead.

Nicotine sulfate will be more abundant in 1943 than in any previous year, because of the tobacco-diversion program undertaken by the United States Department of Agriculture. It is planned to divert 25 million pounds of low-grade tobacco to the manufacture of nicotine insecticides. On the basis of a 3-per cent content of extractable alkaloid, this quantity of tobacco will yield 1,875,000 pounds of nicotine sulfate solution (40 per cent nicotine). This will appreciably augment the normal supply of 2,500,000 pounds.

Of the other materials that promise to be abundant, particular attention is directed to sodium fluosilicate. This compound is easily made from silicon tetrafluoride, a byproduct in the manufacture of phosphatic fertilizers. In the past the consumption of this compound as an insecticide has fallen below that of sodium fluoride—for example, 2 million pounds as compared to about 5 million in 1941. Sodium fluosilicate has proved an acceptable substitute for sodium arsenite in grasshopper bait, and has been used extensively in Mormon cricket baits. Its dusting qualities are greatly improved by fine grinding and the addition of a conditioner. Sodium fluosilicate may prove suitable for application to certain crops, especially in arid regions, and thus augment our supply of other insecticides.

CONCLUSION.—It must be emphasized that the supply picture has changed markedly from time to time in the past and will change often in the future. The growing demands of war eat more and more into civilian economy. Materials abundant today may be scarce tomorrow. It is highly important to have several materials for the control of any given insect, so that when one insecticide becomes scarce others can be substituted. Attention should be given to synthetics, such as phenothiazine, xanthone, phenoxathiin, chlorofluorene, phthalonitrile, and many others. Most synthetics are made from materials that are abundant, such as coal tar, natural gas, petroleum, products of domestic plants, or even from air, water, limestone, and coal, but supplies of even these materials may be restricted because of difficulties of manufacture due to war conditions. Hence, only by testing numerous materials will the entomologist be able to combat insect enemies of vital food crops as the supply of present insecticides is diverted to essential military needs.

The War Production Board appreciates the importance of food for civilians as well as for the armed forces, and is aware of the necessity for using insecticides and fungicides to protect growing crops. Supplies of chemicals for the control of agricultural pests have been made available thus far, and it is believed that, with the exception of imported rotenone and pyrethrum, sufficient ammunition will be assured to fight the attacks of agriculture's chief enemies.—6-16-43.

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Reversals in Order of Effectiveness of Insecticides

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Reversals in the order of effectiveness of two insecticides tested at single dosages sometimes occur in different localities or in different years in the same locality. In the case of derris dust and dual-fixed nicotine dust applied to control the European corn borer, such a reversal has been noted. Batchelder *et al.* (1937) found that dual-fixed nicotine dust was more effective than dust containing rotenone. Baker & Questel (1939) found that dual-fixed nicotine dust (4 per cent nicotine) was at least as effective as derris dust (0.8 per cent rotenone) in 1937, but that derris dust (1 per cent rotenone) was substantially better than the nicotine preparation (3.85 per cent nicotine) in 1938. Turner (1942) reported that dual-fixed nicotine (4 per cent nicotine) was consistently more effective than derris dust (1 per cent rotenone). It should be noted that in all these cases the dosage was measured as concentration in the dust and not as amount deposited on the plants.

The successful use of dosage series in comparing dual-fixed nicotine and nicotine bentonite dusts (Turner 1942) led to the application of the same principles to compare derris and dual-fixed nicotine dusts. Marcross corn was planted April 17 and dusted June 10, 16, 20 and 25. At the time of the first treatment most of the plants were in the mid-whorl stage, and in the late tassel stage when treatment was completed. The peak of egg deposition was about June 13, and of hatching about June 19.

The plots were four rows about 25 feet long and treatments were randomized in blocks with four replications. Twenty plants from the center rows of each plot were used as a sample. Dissection was made just before the roasting ear stage, and the number of larvae in each stalk and each ear recorded.

The dusts were mixed using a clay diluent and pure ground derris root (4 per cent rotenone) to contain 0.25, 0.5, 1.0 and 2 per cent rotenone. The dual-fixed nicotine dust was prepared commercially to contain 1, 2, 4 and 8 per cent nicotine, with a clay diluent.

A summary of the results is presented in table 1, and plotted on the logarithmic probability grid in figures 1 and 2, with dosage used in terms of the concentration applied. In order to facilitate comparison 4 per cent nicotine and 1 per cent rotenone have been plotted at the same point on the abscissa, because these are nearest the dosages usually compared in previous single-dose tests. As the curves are drawn, they cross at approximately 0.7 per cent rotenone and 3 per cent nicotine for plants as a whole, and 0.3 per cent rotenone and 1.25 per cent nicotine for ears only. The superior protection of ears by the nicotine preparation was noted previously by Batchelder *et al.* (1937). Below the point of crossing derris was more effective than nicotine, above it nicotine was more effective than derris.

Table 1.—Control of European corn borer.

Material	Concentration	Total Larvae		Reduction	
		Plant	Ears	Plant	Ears
	Nicotine				
Dual-fixed nicotine	1.0%	791	200	19.8%	20.0%
	2.0	662	156	32.9	37.6
	4.0	457	92	53.7	63.2
	8.0	264	52	73.2	79.2
	Rotenone				
Derris	0.25%	772	224	21.8%	10.4%
	0.5	599	156	39.3	37.6
	1.0	505	123	48.9	50.0
	2.0	361	95	63.4	62.0
None	—	987	250	—	—

It should be emphasized that the point of crossing as discussed here is based on comparison of 4 per cent nicotine with 1 per cent rotenone. If any other concentrations were selected as a point of reference, any crossover would occur at some other place on the curves. This does not change the basic fact that the dosage-response curve for nicotine is steeper than the one for rotenone. Therefore low concentrations of rotenone should perform relatively better than low concentrations of nicotine. Of course the reverse would be true of high concentrations.

Analysis of variance, using probits for the control in individual plots, showed that in the case of the entire plant curvature was negligible and there was a significant difference in slope. In the case of

ears the difference in slope was not significant due to the low value for 0.25 per cent dosage of rotenone.

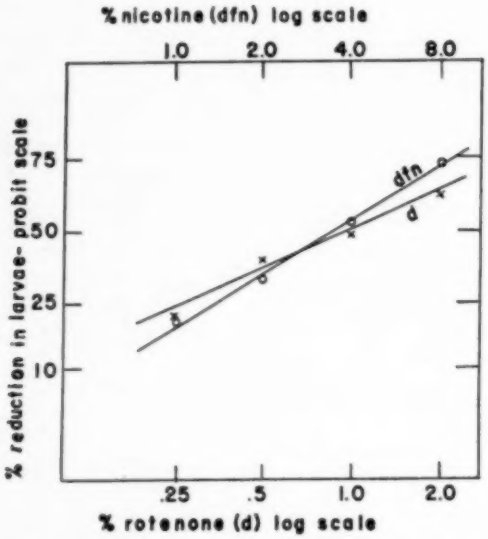

FIG. 1.—Dosage-response curves for dual-fixed nicotine (dfn) and rotenone in derris (d) for control of the European corn borer in the entire plant.

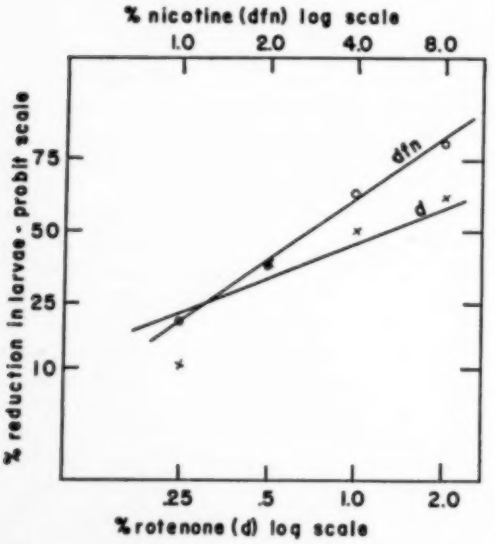

FIG. 2.—Dosage-response curves for dual-fixed nicotine (dfn) and rotenone in derris (d) for control of the European corn borer in ears only.

Crossing dosage response curves have been described by Shepard *et al.* (1937) for fumigants and by Dimond *et al.* (1941) for fungicides. The fact that curves for the two materials cross over means that at single dosages above and below the crossing point the order of effectiveness is reversed. In the present experiment, the point of crossing of the curves for the plants is near the concentrations used in previous single-dosage tests. This suggests the possibility that the reversals in order of effectiveness have been due to a shifting of the point of crossing. It must be stated here that there is no evidence of any change in order of effectiveness of any two insecticides that cannot be accounted for in some way. Thus if 0.5 gram of fixed nicotine deposited on a corn plant is more toxic in one case than 0.125 gram of rotenone in derris root, it should be more toxic in all cases. Unfortunately it is seldom possible in field tests to determine the amount of insecticide actually effective in protecting the plant. It has been the practice to measure the results in terms of the amount of toxicant delivered from the duster. In some cases this is satisfactory, in others, such as the one under discussion, it has ignored both volatility and tenacity which are so drastically affected by changes in temperature and rainfall.

Since no data on actual deposits of the materials in question are available, it is necessary to discuss the results in terms of the amount applied, and to consider factors which might affect the point of crossing of curves using this figure as dosage.

Two types of change may be involved: (1) a change in slope of the curves or (2) a change in position. Further, the change must be greater for one material than the other to influence the point of crossing. This limits the search to consideration of factors which might have a differential action on the two materials.

Dimond *et al.* (1941) have discussed the factors affecting both slope and position of dosage-response curves for fungicides. Slope is affected (1) by environmental conditions acting on the fungus and (2) by coverage of the plant by the fungicide. While it is conceivable that either of these factors could act differentially on dual-fixed nicotine and derris, the experimental evidence available does not indicate such an action.

Position of dosage-response curves (as measured by the dosage required to kill 50 per cent, 95 per cent or any other proportion) is known to be affected by the

size of the population to be controlled (Dimond *et al.* 1941), and by tenacity or resistance to weathering (Heuberger 1940). There is no evidence of a possible differential effect of the population level on corn borer insecticides. Heuberger (1940) has shown that when fungicidal deposits are weathered by washing, the position of the dosage-response curve is shifted to the right, but the slope is not changed.

The method of application of corn borer spraying with water for a uniform time in a precision sprayer and exposed to dust in the dust settling tower described by Heuberger & Turner (1942). After drying, the amount of deposit was determined by weighing. The slides were then washed in a large pan of water according to Heuberger's (1940) method, which was modified by using a geometric series of strokes from 1 to 32.[1] After drying, a second weighing allowed computation of the amount of material resisting washing. The

Table 2.—Tenacity of Residues.

No. of Strokes of Washing	Dual-fixed Nicotine grams			Derris-Clay Dust grams		
	Deposit	Residue	Per Cent Tenacity	Deposit	Residue	Per Cent Tenacity
1	0.0235	0.0113	48.1	0.0178	0.0083	46.1
	.0205	.0103	50.2	.0187	.0062	33.2
	.0209	.0100	47.8	.0208	.0086	41.3
2	0.0236	0.0068	28.8	0.0184	0.0067	36.4
	.0210	.0057	27.1	.0194	.0052	26.8
	.0198	.0046	23.2	.0206	.0072	34.9
4	0.0239	0.0053	22.2	0.0181	0.0066	36.5
	.0240	.0040	16.7	.0189	.0042	22.2
	.0207	.0038	18.4	.0168	.0038	22.6
8	0.0231	0.0046	19.9	0.0193	0.0050	25.9
	.0247	.0031	12.6	.0194	.0045	23.2
	.0206	.0033	16.0	.0195	.0043	22.1
16	0.0219	0.0032	14.6	0.0210	0.0051	24.3
	.0200	.0022	11.0	.0221	.0038	17.2
	.0209	.0017	8.1	.0170	.0038	22.4
32	0.0214	0.0035	16.4	0.0194	0.0056	28.9
	.0205	.00175	8.3	.0201	.0031	15.4
	.0206	.0013	5.8	.0180	.0032	17.8

insecticides as well as the type of materials most effective indicates a stomach-poison action. Therefore the resistance to weathering of the insecticidal deposits on the corn plant is of importance. In wet seasons, the dosage-response curve of a material with low tenacity should be displaced farther to the right (more required to control a given percentage) than the curve of a material with high tenacity. This would automatically shift the point of crossing to the right. In dry seasons the reverse would be true, and this point of crossing would shift to the left.

The tenacity of the two materials was studied in the laboratory. Clean glass lantern slides were weighed, moistened by

results of three replications of this test for dual-fixed nicotine dust (4 per cent nicotine) and dust containing one per cent rotenone are given in table 2. The individual points have been plotted on the logarithmic probability grid in figure 3. Except at one stroke of washing, dual-fixed nicotine dust showed distinctly less tenacity than derris dust. In terms of amount of washing to remove 80 per cent of the deposit, approximately 25 strokes for derris dust equalled 4 strokes for the nicotine preparation. Hence derris dust was about 6 times as resistant to washing as dual-fixed nicotine.

[1] Method suggested by J. G. Horsfall, Plant Pathologist, Conn. Agr. Expt. Sta., to avoid comparison of percentage tenacity.

Analysis of the residues after washing[1] indicated that approximately 0.5 per cent rotenone remained in the residue on the derris slides. No nicotine was detected in the residue from dual-fixed nicotine. However, this does not mean that no nicotine was left, because the expected amount would be less than 0.0002 gram per slide,

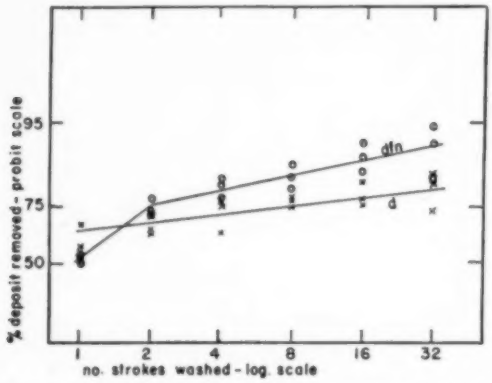

FIG. 3.—Tenacity curves for dual-fixed nicotine (dfn) and derris (d) for different amounts of washing.

which is too small for accurate determination. Some of the nicotine is known to be water-soluble, and would certainly be removed by washing.

These data indicate a marked difference in tenacity of derris dust and dual-fixed nicotine dust. The results in figures 1 and 2 indicate the relative toxicity of the two materials as affected by the rainfall in this test. With less rain than in 1942, the point of crossing of the two curves should be lower, because the nicotine should perform relatively better. With more rain the point of crossing would be higher. Only a slight shift would be necessary to make the cross-over occur above 4 per cent nicotine and 1 per cent rotenone. This fact supplies the differential effect needed to account for reversals in order of toxicity of the two materials used in single dosage tests.

DISCUSSION AND SUMMARY.—The results of tests of dual-fixed nicotine dust and derris dust in dosage series shows that the dosage response curves cross at approximately 0.7 per cent rotenone and 3 per cent nicotine. Below these dosages derris was more effective, above them nicotine. Reversals in order of effectiveness of the two materials tested at single dosages have been reported. The most obvious factor which might act differentially on the two materials is rainfall. Differences in tenacity determined in the laboratory indicated that derris dust resisted about six times as much washing as the nicotine material and should therefore perform relatively better in seasons of a high amount of rainfall. Improvement in tenacity of the nicotine preparation should offset this differential effect.

It is suggested that reversals in order of effectiveness of other insecticides may be due to a similar type of reaction which would explain logically reversals in different seasons or in different areas in the same season.—5-5-43.

[1] Analysis by H. J. Fisher, Conn. Agr. Expt. Sta.

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Toxicity of Derris, Nicotine, and Other Insecticides to Eggs of the Housefly and the Angoumois Grain Moth

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An investigation was made to determine the toxicity of derris, nicotine and some of its compounds, and other materials to the eggs of the housefly, *Musca domestica* L., and the Angoumois grain moth, *Sitotroga cerealella* (Oliv.). Approximately 750 tests were made on about 110,000 eggs of the housefly and 150 tests on 20,000 eggs of the grain moth.

MATERIALS AND METHODS.—The various materials tested and their concentrations are given in table 1. The derris powder and most of the nicotine compounds were furnished by the Division of Insecticide Investigations. The eggs of the housefly were obtained from a laboratory culture (Richardson 1932); those of the grain moth came from adults supplied by the Division of Fruit Insect Investigations.

The methods of testing were similar to those used by Breakey and Miller (1935a). From 75 to 150 (or more) eggs were dipped for 10 to 12 seconds in a test tube containing a solution of the material at 70° F. Housefly eggs were used when 1½ to 5 hours old and then placed in petri dishes in a cabinet at 80° F. and 95 to 100 per cent relative humidity. Some of the petri dishes were covered so that any fumigating action could be detected. Counts of hatched and unhatched eggs were made 24 to 48 hours later. Eggs of the Angoumois grain moth were used at various ages and then transferred to covered petri dishes and incubated in a cabinet near 70° F. and 50 to 60 per cent relative humidity. Grain moth eggs began to hatch on the sixth day, the majority hatched on the seventh day, and final counts were made on the tenth or eleventh day. In untreated checks from 5 to 15 per cent of the housefly eggs and 20 to 30 per cent of the grain moth eggs were found to be infertile, and these were taken into account in calculating the net mortality. The possible action of the chemicals against larvae during and after hatching was not considered in these studies.

RESULTS WITH HOUSEFLY EGGS.—The results of dipping housefly eggs are summarized in table 1.

The aqueous derris-powder suspension was the most effective material tried. Since pyridine was toxic only in covered petri dishes, a fumigation effect was indicated.[2] Pine oil, oils derived from the dry distillation of various plant products, and the lauryl thiocyanate mixture showed a similar action, although the last named was also fairly toxic in uncovered dishes. The nicotine salt with 4,6-dinitro-o-cresol showed some toxicity. The pyrethrins, anabasine, nicotine and its compounds, and undiluted petroleum oil showed little effectiveness at the concentrations tested. Free nicotine appeared slightly more effective than nicotine sulfate.

Although nicotine did not seem to be highly efficient as judged by the percentage of unhatched eggs, a number of other individuals appeared to have died in the process of hatching.[3] These individuals were not included in the efficiency calculation, although if they had been nicotine would still not appear highly effective against eggs up to 5 hours of age. Further tests indicated that nicotine was more effective against eggs 1 to 2 hours old,[4] but efficiency decreased rapidly until little or no kill occurred with eggs 24 to 25 hours old. Of course these older eggs were exposed to the poison a much shorter time before they hatched.

Because of the high efficiency of the derris-powder suspension, further tests were made with suspensions of derris extractives and of pure rotenone. They were prepared by diluting an acetone solution containing 1 gram each of rotenone and tannic acid (stabilizer) per 100 cc. (Jones

[1] H. A. Jones, C. R. Smith, L. M. Markwood, and D. L. Vivian, of this Bureau, provided analyzed samples of derris root, nicotine compounds, and other materials; H. Spencer supplied adults of the Angoumois grain moth; and A. M. Phillips gave part-time asistance in toxicity tests.

[2] Jewson & Tattersfield (1922) have discussed the fumigating action of pyridine against mites and their eggs, but Tattersfield & Gimingham (1927) report that pyridine applied as a spray had little toxicity to the comparatively susceptible *Aphis rumicis* L.

[3] Some of these individuals may have been unhatched nearly mature eggs—killed by the poison—which became distended shortly after death and broke the eggshell. O'Kane *et al.* (1931) have reported considerable distention of nicotine-treated cockroaches after death.

[4] Individuals that died in hatching were included in this rating. These results corroborate to some extent those of Apple (1941), who reported 85% kill of eggs up to 3 hours old by a 1.67% nicotine solution. This somewhat higher efficiency may be due to Apple's use of a higher temperature and fewer eggs per test.

Table 1.—Efficiency of various materials against housefly eggs 1½ to 5 hours old. Eggs were dipped for 10 to 12 seconds at 70° F. and incubated in covered and uncovered Petri dishes at 80° F.

Mortality Range, Per Cent	Material[1]	Concentration, Per Cent by Weight
90–100	Derris powder (3.6% rotenone, 16% total extractives) suspension	0.275
	Oil from dry distillation of wood in acetone (*F*)[2]	2.0
	Pyridine in acetone (*F*)	15.0
70–90	Mixture of lauryl and other thiocyanates, plus wetting agent (*F*)[3]	.16
	Nicotine, salt with 4,6-dinitro-o-cresol (45.0% nicotine) in 33% pyridine solution[4]	3.3
30–70	Nicotine	10.0
	Nicotine, salt with 2-chloro-4,6-dinitrophenol (42.9% nicotine) in 33% pyridine solution[4]	3.3
	Nicotine, salt with 2-cyclohexyl-4,6-dinitrophenol (37.9% nicotine) in 33% pyridine solution[4]	3.3
	Oil from dry distillation of peanut shell in acetone (*F*)	2.0
	Pine oil (steam-distilled) emulsion in 0.25% sulfonated castor oil solution (*F*)[1]	1.0
0–30	Acetone	100.0
	Anabasine	3.0
	4-(p-Bromophenylazo)-phenol in 20% acetone solution	.01
	4-(2,5-Dichlorophenylazo)-m-cresol in 20% acetone solution	.01
	4-(2,5-Dichlorophenylazo)-o-cresol in 20% acetone solution	.01
	4-(2,5-Dichlorophenylazo)-l-naphthol in 20% acetone solution	.01
	p-(2,5-Dichlorophenylazo)-phenol in 20% acetone solution	.01
	Ethyl alcohol	100.0
	Kerosene, highly refined, emulsion in 0.5% higher sulfated alcohol solution	5.0
	Petroleum oil, highly refined[5]	100.0
	Nicotine, in water or in 0.25% soap solution	5.0
	Nicotine sulfate	5.0
	Nicotine in 33% pyridine solution[4]	3.0
	Nicotine binoxalate (47.4% nicotine)	8.3
	Nicotine bromostearate in 5% kerosene emulsion	.5
	Nicotine, salt with 2-chloro-4,6-dinitrophenol (42.9% nicotine)	.2
	Nicotine, salt with 2,4-dinitrophenol (46.8% nicotine) in 33% pyridine solution[4]	3.3
	Nicotine, salt with 2,4-dinitro-6-phenylphenol (38.4% nicotine) in 33% pyridine solution[4]	3.3
	Nicotine ditartrate (32.7% nicotine) in 33% pyridine solution[4]	10.0
	Nicotine humate (32.7% nicotine) in 33% pyridine solution[4]	10.0
	Nicotine hydrochloride, compound with zinc chloride (48.0% nicotine)	2.0
	Oil from dry distillation of tobacco stem in acetone	2.0
	Pyrethrins I and II	.04
	4′-o-Tolylazo-l-o-tolylazo-2-naphthol in 20% acetone solution	.01

[1] The solvent was water unless otherwise noted.

[2] *F* indicates that efficiency was probably due to a fumigating action in covered petri dishes. Efficiency was much less or negligible when eggs were held in uncovered petri dishes.

[3] Proprietary mixture believed to contain 50% of thiocyanates; the percentage of thiocyanates in the diluted spray would therefore be 0.083.

[4] Tested only in uncovered dishes to avoid fumigating action of pyridine.

[5] Viscosity 84 seconds Saybolt at 100° F., specific gravity 10.85 at 20° C., unsulfonatable materials 99.2%.

and Davidson 1931). Suspensions of derris extractives (3.5 grams of extractives to each gram of rotenone) were equal in toxicity to derris-powder suspensions of the same rotenone content. Derris powder gave a kill of 90 to 98 percent and derris extractives a kill of 90 per cent in suspensions containing 0.01 per cent of rotenone, and kills of 99 and 97 per cent, respectively, in suspensions containing 0.02 per cent of rotenone. The pure-rotenone suspensions were also very toxic. At concentrations of 0.0033, 0.002, 0.001, and 0.00025 per cent the kills were 83, 73, 64, and 34 per cent, respectively, as compared with 70, 68, 49, and 17 per cent when suspensions of derris extractives were used at similar concentrations. The small difference in favor of rotenone, which is unexpected, may be due to a difference in the degree of dispersion.

The filtrate obtained when a derris-powder suspension (0.01 per cent rotenone) was filtered through No. 5 Whatman paper killed 41 to 72 per cent of the eggs. Colloidal material evidently came through the filter paper, but when this was removed from other samples by passing them through an unglazed porcelain filter or centrifuging 30 to 60 minutes at 3000 r.p.m. (radius of centrifuge arm 7 inches), the resulting solutions still gave 33 to 44 per cent kill. Derris powder evidently contains some water-soluble material that is toxic to the eggs, although some of this toxicity may be due to rotenone, which is very slightly soluble in water.[1] A water suspension of the marc obtained after filtering a derris-powder suspension containing 0.02 per cent of rotenone killed 96 per cent of the eggs dipped in it.

Suspensions of derris extractives containing 0.002 to 0.02 per cent of rotenone retained their toxicity for 9 days after preparation and possibly retain it for longer periods. Derris-powder suspensions appeared to have a similar stability.

Suspensions of derris or other rotenone-containing products may be worth testing in the control of housefly eggs, as well as those of cabbage and onion maggots.

An acetone extract of *Tephrosia piscatoria* containing 2.7 per cent of extractives was also found to be toxic to housefly eggs. Water suspensions containing 0.5 and 1.0 per cent of the extract gave 18.6 and 46.9 per cent mortality. An acetone extract of the marc of *T. virginiana* pre-

[1] For data on the chemical analysis of the water extracts of derris see Goodhue and Haller 1939.

viously extracted with ether was also toxic, a 50 per cent suspension in water giving 91.0 per cent mortality.

RESULTS WITH ANGOUMOIS GRAIN MOTH EGGS.—The effectiveness of various materials against the Angoumois grain moth is shown in figure 1.

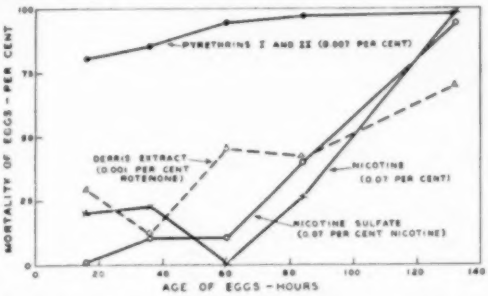
MORTALITY OF EGGS - PER CENT
AGE OF EGGS - HOURS
PYRETHRINS I AND II (0.007 PER CENT)
DERRIS EXTRACT (0.001 PER CENT ROTENONE)
NICOTINE (0.07 PER CENT)
NICOTINE SULFATE (0.07 PER CENT NICOTINE)

FIG. 1.—Ovicidal action of various insecticides against Angoumois grain moth eggs of various ages.

At the concentrations tested nicotine, nicotine sulfate, and derris extract were relatively ineffective against young eggs but became progressively more toxic to older eggs. On the other hand, the pyrethrins were toxic even to young eggs and showed increasing toxicity to older eggs. A second series of tests corroborated these results. Free nicotine and nicotine sulfate showed a similar efficiency, but were less toxic than the other two materials. Whether the efficiency was due mainly to a fumigation action was not determined. The pyrethrins appeared to be about 10 times as toxic as nicotine to old eggs but were relatively more toxic to young eggs.

It is probable that, on the basis of its rotenone content, derris extract is the most toxic of the four materials to older eggs. Similar results were obtained by Breakey and Miller (1935b) with rotenone and other insecticides on grain moth eggs 48 hours old. The pyrethrins may be the most toxic to very young eggs, but further tests should be made.

SUMMARY.—Various materials were tested as dips against eggs of the housefly and the Angoumois grain moth. Against housefly eggs 1½ to 5 hour old suspensions of derris powder, derris extract, or rotenone were found to be the most effective. The pyrethrins, anabasine, nicotine and nicotine compounds, petroleum oil, and other materials tested showed little toxicity. Nicotine showed greater efficiency against very young eggs, 1 to 2 hours old. Pyridine, pine oil, oil derived from the dry distillation of various plants, and a lauryl thiocyanate mixture were effective in covered petri dishes, an indication of a fumigating action. Derris powder apparently contained water-soluble materials toxic to the eggs in addition to the small quantities of soluble rotenone. The marc remaining after one water extraction was still toxic. Water suspensions of derris extractives or powder appeared to be fairly stable. Extracts from *Tephrosia piscatoria* and *T. virginiana* were also toxic.

Against Angoumois grain moth eggs pyrethrins I and II at a concentration of 0.007 per cent were much more toxic than nicotine or nicotine sulfate at 0.07 per cent, or derris extract containing 0.001 per cent of rotenone, when the eggs were early in incubation, but all these were highly effective against older eggs.—5-5-43.

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The Relative Resistance of *Periplaneta americana* and *Blattella germanica* to Pyrethrum Spray

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The relative resistance of insects that frequent the same habitat and are controlled by insecticidal treatment is an important factor in control operations. Such a situation is often encountered in efforts to control the American cockroach, *Periplaneta americana* (L.), and the German cockroach, *Blattella germanica* (L.), with pyrethrum sprays. To obtain some data on this subject, an investigation was made to determine the relative resistance of these two species to spray deposits of deodorized kerosene containing pyrethrum.

Since it has been reported that the adult females of *Blattella germanica* (Woodbury 1938) and *Periplaneta americana* (McGovran *et al.* 1941) are more resistant than the males of the same species, the comparisons were made with adult females and large nymphs of both sexes. These are the most resistant forms of the active insects, but the eggs of *B. germanica* were found by Parker & Campbell (1941) to be more resistant to pyrethrum spray than the adult females.

The insects used in these tests were reared in the laboratory at Beltsville, Md., on water and a commercial dry dog food. The adults were of various ages and were selected for testing if they appeared normal. The large nymphs used were as nearly uniform in size as could be secured by visual selection.

A direct spray was applied by the pendulum method (McGovran and Fales 1942) to the dorsal surface of the insects confined in a circular container ($3\frac{1}{2}$ inches in diameter and $2\frac{1}{2}$ inches deep) with vertical sides. The spray was applied intermittently over a period of approximately 15 seconds. Two minutes after the spraying was started the insects were transferred to 6-inch Petri dishes with screen covers, supplied with food and water, and held at 75° F. and 50 per cent relative humidity while observations were made for knockdown and mortality.

Periplaneta americana was sprayed in groups of 5, segregated by stage and sex, but *Blattella germanica* was sprayed in groups of 15 to 25, each group containing male and female adults and large nymphs. The average weight of the nymphs of *P. americana* was 950 milligrams, as compared with 65 milligrams for *B. germanica*. The spray used contained 5 milligrams of the pyrethrins[1] per milliliter of kerosene; its specific gravity was 0.79.

A deposit of this spray that caused approximately 75 per cent mortality of adult female *Blattella germanica* and a slightly lower mortality of nymphs knocked down 100 per cent in 5 minutes. A deposit that caused similar mortalities of the same stages of *Periplaneta americana* caused no knockdown in 5 minutes; 35, 55, and 95 per cent in 10, 15, and 30 minutes, respectively, of adult females and male nymphs, and 0, 15, and 50 per cent knockdown of female nymphs in the same periods. Heavier deposits that caused higher mortalities increased the speed of knockdown, but even when 100 per cent mortality was obtained with both species, the rate of knockdown was much faster for *B. germanica*.

In a series of 20 tests with adult females of each species a deposit of 270 micrograms per square centimeter caused 72 per cent mortality of *Periplaneta americana* in 7 days, as compared with 54 per cent mortality of *Blattella germanica* in the same period from a deposit of 486 micrograms. It will thus be seen that the deposit to kill *B. germanica* would be roughly twice that required to kill *P. americana*.

In a series of 26 tests each with adult females and nymphs of both species, a deposit of 270 micrograms per square centimeter caused 68 and 54 per cent mortality of the respective stages of *Periplaneta americana*, and a deposit of 540 micrograms per square centimeter killed 76 per cent of the adult female and 63 per cent of the nymphs of *Blattella germanica*.

A further comparison of tests at this ratio of deposit is shown in table 1. Each

[1] The authors wish to express their thanks to the Divison of Insecticide Investigations of this Bureau for determining the pyrethrin content of this spray.

mortality in this table is the average of 6 or 10 tests.

The data in table 1 indicate that the adult females and large nymphs of *Blattella germanica* were more resistant to the pyrethrum spray than those of *Periplaneta americana*, but that twice the deposit applied to the latter when applied to the former caused in most instances a slightly higher mortality. Under the conditions of this investigation a deposit of pyrethrum spray that caused a certain mortality of *B. germanica* could in most instances be reduced one-half and still cause about the same mortality of *P. americana*. Equal deposits applied to both species gave an average mortality that was 26 per cent higher for *P. americana*. However, as insects' resistance to insecticides varies from time to time and from one location to another and is influenced by numerous factors, it is obvious that a comparison of the relative resistance of two species would vary in accordance with the factors affecting each.

Table 1.—Mortality of *Periplaneta americana* and Blattella germanica following treatment with a pyrethrum spray containing 5 mg. of pyrethrins per milliliter of deodorized kerosene.

State of Insect	Spray Deposit, Micrograms Per Square Centimeter	Per Cent Mortality[1]	
		P. americana	*B. germanica*
Adult females	960	—	100
	560	100	72
	280	56	27
Large nymphs	960	—	87
	560	77	60
	280	52	25

[1] Differences larger than 25 per cent are significant.

In general the large nymphs were more resistant than the adult females of the same species, although the 280-microgram deposit gave practically the same mortality for both stages. Parker & Campbell (1941) stated that large nymphs of *Blattella germanica* were more resistant than adults, but McGovran & Fales (1942) found the adult females to be more resistant. This difference may have been due to the age of the insects used. Tuma (1938) demonstrated that the age of *B. germanica* influenced their resistance to liquid insecticides. He found these insects to be most resistant when 17 weeks old.

Comparisons of the resistance of *Blattella germanica* and *Periplaneta americana* were made only with a pyrethrum extract dissolved in deodorized kerosene. It should not be assumed from these data that *B. germanica* is more resistant to all insecticides, as this may not be the case.

SUMMARY.—A pyrethrum spray that contained 5 milligrams of pyrethrins per milliliter of deodorized kerosene was applied by the pendulum method as a direct spray to the dorsal surface of reared cockroaches. Adult females and large nymphs of *Blattella germanica* (L.) were knocked down more rapidly than similar stages of *Periplaneta americana* (L.), but mortality counts showed that *B. germanica* was more resistant to the lethal effect of the spray. Twice the deposit applied to *P. americana* caused only slightly higher mortalities when applied to *B. germanica*. —7-28-43.

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Ethylene Dichloride Treatments for the Immature Stages of the Japanese Beetle

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A number of chemical treatments have been developed and authorized by the United States Department of Agriculture (1939) for the elimination of the Japanese beetle, *Popillia japonica* Newm., in the soil about the roots of plants. These treatments, which are employed as a basis for quarantine certification, involve the use of lead arsenate, paradichlorobenzene, naphthalene, carbon disulfide, ethylene oxide, hydrocyanic acid, or methyl bromide. Since the fall of 1940 a number of compounds have been evaluated for the purpose of developing other treatments for the elimination or control of this insect. During the winter of 1940–41 it was established by the Moorestown, N. J., laboratory[2] that low dosages of ethylene dichloride, used as a dip in the form of an emulsion, are highly toxic to third instars of the Japanese beetle. Further investigations have resulted in the development and authorization by the United States Department of Agriculture (1942) of a method for the treatment of balled and potted plants with this emulsion. These latter investigations regarding the effect of ethylene dichloride, applied in several ways, on the immature stages of the beetle, and also on plants in various environments, are described in this paper.

ETHYLENE DICHLORIDE EMULSION.—Ethylene dichloride emulsion was prepared from an emulsible mixture of this compound, the formula for which is as follows:

Potassium hydroxide (C.P.)	2.5	pounds
Ethyl alcohol (190 proof)	14.0	"
Water	6.0	"
Oleic acid (crystal white olein)	17.5	"
Ethylene dichloride (commercial)	60.0	"

The following directions have been given for the preparation of this emulsible mixture and the emulsion:

Mix the several ingredients in the order given in the formula. Dissolve the potassium hydroxide in the alcohol and water, add the oleic acid, and stir intermittently for about 10 minutes. Compensate for evaporation loss by the addition of alcohol and water in the ratio given in the formula. Add the ethylene dichloride and stir.

The emulsible ethylene dichloride shall have a specific gravity of about 1.070 at 77° F. and contain 60 per cent by weight of ethylene dichloride, It shall be a clear solution that may be readily diluted with water to form a uniform, stable, milklike emulsion. The product should be kept in gastight containers in a cool place at a temperature above 40° F. At lower temperatures it will separate into layers, in which case it must be warmed to room temperature and stirred to restore it to its original and usable condition.

To dilute the emulsible ethylene dichloride, add small quantities of water successively, stirring continually until a uniform, creamlike emulsion is formed. Dilute this emulsion with the remainder of the water and stir a few minutes to insure a uniform suspension. This emulsion must be prepared immediately before using.

The dilutions given in this paper refer to the emulsible mixture. For example, a concentration of 1 gallon of the emulsible mixture in 100 gallons of water is expressed as "1:100."

BALLED AND POTTED PLANTS.—Studies were made to establish the toxicity of various quantities of the emulsible mixture of ethylene dichloride, diluted and used as a dip, to the larval stages of the Japanese beetle in balled and potted plants. Factors considered included the duration of the immersion, effect of temperature, moisture, soil types, ball sizes, ball coverings, and postimmersion effect. For the purpose of the study, use was made largely of azalea plant balls ranging from 2 to 10 inches in diameter. Some of the plant balls were bare, others were wrapped, and others potted. All had been artificially infested with known numbers of larvae. The infested plant balls were immersed in the dips for various periods, following which they were grouped closely on greenhouse benches or floors at various temperatures and for varying periods of time. The plant balls were then broken down and the larvae not definitely dead, as indicated by partial decomposition, were placed individually in covered sections of 3-inch salve tins containing soil and grass seed. The tins were then placed

[1] The authors gratefully acknowledge the assistance throughout these investigations of L. W. Coles, biological aide, Division of Fruit Insect Investigations, L. Koblitsky, assistant chemist, Division of Insecticide Investigations, and various members of the Division of Japanese Beetle Control.

[2] E. D. Burgess, L. W. Coles, R. D. Chisholm and L. Koblitsky. (Unpublished report, Bur. Ent. and Plant Quar.) 1941.

in a cabinet maintained at 80°±2° F. (a favorable temperature for the development of Japanese beetle grubs), and observations were made at intervals to determine ultimate mortality. Several weeks were often required for this determination.

Preliminary tests established the fact that certain azaleas would tolerate the immersion of the plant balls for at least 10 seconds in an emulsion prepared at the rate of 2 gallons of the emulsible mixture of ethylene dichloride to 100 gallons of water. Detailed tests involving the use of more than 20,000 larvae established the fact that an emulsion prepared at the rate of 1 gallon of the emulsible mixture of ethylene dichloride to 100 gallons of water was sufficiently toxic, under certain conditions, to kill all the larvae. An emulsion at one-half this strength was equally effective in many cases. Maximum effectiveness was obtained if the balls were immersed in the emulsion for 10 seconds. The effectiveness of the treatment was further dependent on postimmersion conditions. It was found necessary to keep the larvae in the plant balls for at least 24 hours following treatment, and retention of the insecticide within the balls for as much of this period as possible was essential. This was accomplished by closely grouping the treated plants on tight greenhouse benches or floors and surrounding the groups with wooden side walls as high as the balls. The influence of the temperature of the dip and of the plant balls at the time of dipping was established from tests wherein the temperature was controlled between 45° and 75° F. in steps of 10°, maintained within ±5° during the postimmersion period. All larvae were killed under each of these conditions, although less time was required when they were treated at the higher temperatures. Toxicity to the larvae was not modified if the moisture content of the plant balls was normal for average plant growth. Plant balls containing an abnormal amount of moisture did not absorb enough of the emulsion to kill all the larvae, and neither did plant balls composed of certain soils, such as peat, when the moisture content was subnormal. Soil type, ball size, and type of ball wrapping also influenced the interval of time required for the larvae to die. Those in muck or heavy loam died more rapidly than those in light sandy loam or peat. Disregarding the influence of soil type, a slightly shorter period was required for larval mortality to occur in large balls than in small ones. Likewise, mortality was produced more rapidly in balls wrapped with a heavy covering, such as burlap, than in bare balls or balls wrapped with a light material, such as Leno cloth. Differences in the rates of penetration of the emulsion into the balls and in the dispersal of the resulting gas may have been responsible for these variations.

Potted plants were treated in the same manner as balled plants. Although the potted plant balls did not absorb so much of the ethylene dichloride emulsion (1:100) during the 10-second immersion period as did the bare plant balls, all the larvae were killed by the treatment. It appears that the pots effectively retained the ethylene dichloride vapor within the plant balls and thus prolonged its insecticidal action during the postimmersion period. An application of the emulsion (1:100) to the surface of the soil at the rate of 100 ml. per 6-inch pot and retention of the larvae in the treated soil balls for at least 48 hours also caused the death of all larvae.

Incidental observations made on other scarabaeid larvae throughout these investigations have indicated that *Autoserica castanea* (Arrow), *Strigoderma arboricola* (F.), and some species of *Phyllophaga* are more resistant to the effects of ethylene dichloride than are Japanese beetle larvae.

Pupae and prepupae of the Japanese beetle were placed in balled or potted plants and treated in the same manner as described above for larvae. In some of the tests, involving about 1,000 pupae, all were killed by immersing the infested plant balls in the emulsion (1:100) for 10 seconds and retaining the pupae in the balls for at least 24 hours. In other tests as many as 10 per cent of the pupae survived. It is indicated that prepupae and those pupae in the early stages of development are killed as readily as larvae and that some of those approaching the adult stage may withstand the treatment and complete their development.

Japanese beetle eggs were placed in artificial soil balls in pots and immersed for 10 seconds in the emulsion (1:100). Following a postimmersion period of

several days, the eggs were removed from the soil and placed individually in depressions cast in moist plaster-of-paris blocks to provide an environment suitable for hatching. About one-third of the eggs in the early stages of development and most of the nearly mature eggs failed to hatch.

In order to determine plant reaction, the balls of 24 varieties of azaleas, 60 kinds of hothouse plants, 40 kinds of perennials, and 28 kinds of trees or shrubs were immersed in the emulsion (1:100) for 10 seconds. Observations over several months indicated that, with the exception of *Genista* sp., injury to these plants by this treatment was negligible.

PLANTS GROWING IN BEDS.—In preliminary tests, applications of ethylene dichloride emulsions prepared at the rates of 1, 2, or 3 gallons, respectively, of the emulsible mixture per 100 gallons of water were made to the surface of the soil about the roots of plants growing in beds in which had been placed known numbers of larvae. The emulsions were applied by means of a sprinkling pot at the rates of 1, 2, or 3 gallons per square yard, followed, in some instances, with applications of water. The treated areas were left undisturbed for several days, the larvae recovered, and mortality determined as previously described. All the larvae died following the application of 2 gallons of the emulsion (1:100) per square yard or 1 gallon (2:100) followed by 1 gallon of water.

TURF.—Turf was treated in a manner similar to that described for growing plants. Treatment of a screened plot (10 feet by 10 feet), infested with 1,500 nearly mature larvae, with the emulsion (1:100) at the rate of 1 gallon per square yard resulted in almost complete control. Only 3 adults emerged, as compared with 330 from a check plot infested with 1,000 larvae. Slight yellowing of the grass but no permanent injury followed the treatment. In other tests several plots of turf of 1 square yard, each plot containing a heavy natural infestation of about 100 larvae per square foot, were treated in triplicate by applying 1 or 2 gallons of the emulsion (0.5, 1, 1.5, and 2:100) with a sprinkling pot and left undisturbed for 2 weeks. In some cases 1 gallon of water was also applied after the emulsion. Mortality determinations were made as previously described. Two gallons of the 1:100 concentration or 1 gallon of the 2:100 concentration followed by 1 gallon of water killed all the larvae. Two gallons of the 0.5:100 concentration or 1 gallon of the 1:100 concentration, followed by 1 gallon of water, resulted in about 95 per cent control, and 1 gallon of the 1:100 concentration resulted in about 90 per cent control. The effectiveness of surface treatments appears to be influenced by both the concentration and volume of the emulsion applied per unit of area.

CHAMBER FUMIGATIONS.—A commercial mixture consisting of 3 volumes of ethylene dichloride and 1 volume of carbon tetrachloride was used. In preliminary tests, third instars were exposed in a fumigation chamber to this mixture vaporized at concentrations of $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and 3 pounds, respectively, per 1,000 cubic feet for 3 hours at a temperature of $70° \pm 1°$ F. A total of 250 larvae were used in each test, as follows: 100 naked individuals placed in perforated cross sections, 100 about the roots of 10 potted azaleas, and 50 in 10 wrapped azalea plant balls. After exposure the naked larvae were transferred at once to fresh soil containing grass seed, whereas those in the plant balls were held as described previously. All the larvae in all the tests were killed. Most of them died within 2 to 3 weeks, although a few survived as long as 5 weeks. This delayed mortality was similar to that observed in the emulsion test described previously. In a similar series of tests all the larvae were killed after exposure for 3 hours to 1.5 pounds of the mixture per 1,000 cubic feet at 80° F., 3 pounds at 60° and 6 pounds at 40°. Below 60° the required dosage and exposure period caused injury to some of the plants.

SUMMARY.—Ethylene dichloride in the form of an emulsion prepared from an emulsible mixture of this compound has been demonstrated to be an effective insecticide for the immature stages of the Japanese beetle. Immersion of balled or potted plant balls as large as 10 inches in diameter, for 10 seconds, in an emulsion prepared at the rate of 1 gallon of the emulsible mixture to 100 gallons of water resulted in mortality of all larvae. Most of the pupae and at least one-third of the eggs were also killed by this treatment. Variable factors such as temperature,

moisture, ball wrapping, and soil type, within the range normally encountered in nurseries, were not limiting factors. On the basis of this evidence, the treatment has been authorized by the United States Department of Agriculture as a quarantine measure for the treatment of balled and potted plants infested with Japanese beetle larvae. Application of the above emulsion at the rate of 2 gallons per square yard to the surface of the soil about the roots of plants growing in beds or to turf killed all the larvae and a high percentage of pupae. Applications to turf of one-half this quantity of emulsion were highly effective. Injury to plant growth by these treatments was negligible.

As a fumigant in an enclosed chamber the vapors of an ethylene dichloride-carbon tetrachloride mixture gave promising results in preliminary trials at temperatures above 60° F.—5-10-43.

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Fumigation of Camellias and Azaleas with Methyl Bromide

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Methyl bromide has been widely used as a fumigant since Mackie and Carter (1937) reported on its use for the fumigation of vegetables and ornamental plants. Although the literature is too familiar to warrant an extensive review, of particular interest is the work of Hawkins (1938) (1939), Donohoe and Johnson (1939), Latta and Cowgill (1941) on greenhouse and ornamental plants, and the work of Livingstone and Swank (1941) on camellia and azalea pests. Ritcher (1941) developed the use of methyl bromide for the destruction of the strawberry crown borer, *Tyloderma fragarie* (Riley), in living plants.

Work at this Station with methyl bromide was started in 1938. In the first experiments a *Masonite* chamber with a capacity of 50 cubic feet was used. The chamber was open at the bottom so that it could be placed over the plants to be fumigated. Moist soil was heaped up around the outside to reduce the escape of the gas, and a fan was operated inside throughout the exposure period. Perfect kills of camellia scale, *Lepidosaphes camelliae* Hoke, and tea scale, *Fiorinia theae* Green, on camellias were obtained without injury to the plants. Although the temperature could be controlled within a few degrees during any one exposure period by placing a wet canvas over the chamber, it soon became evident that a chamber equipped for temperature control would be necessary for further progress and the ultimate practical application of the fumigant.

This paper reports the results of an extensive series of tests designed to integrate the temperature, exposure, and dosage requirements for a perfect kill of the pests in question, to establish plant tolerances, and to apply the results to nursery practice.

EQUIPMENT.—Most of the experiments were carried out in an insulated chamber lined with galvanized sheet iron and having a capacity of 150 cubic feet. The joints, which were made on the studs and plates, were made gas tight by the liberal use of plastic roofing cement and a 1 by 2 inch strip of wood nailed over each. Quarter-round wood strips were used in the corners. A false floor made of wood slats supported the load about 2 inches above the sheet iron floor. To heat the chamber, convection heaters were constructed by mounting 200-watt light bulbs on a narrow strip of wood in the bottom of a box, open at the top and bottom. A sheet iron jacket supported inside by knobs about 1 inch from the wall of the box and 0.5 inch from the bulbs absorbed radiation from the bulbs and increased the efficiency of the heater. The whole unit was supported on legs 3 inches above the floor of the chamber to allow circulation of air

through the heater. One or more of the bulbs could be unscrewed, thus providing flexible units that could be adapted to the load and to the prevailing atmospheric temperature. One heating unit of 4 bulbs was operated by a relay and thermostat, and a second unit was connected to a manual switch outside of the chamber. The thermostat[1] had a sensitivity rating of 0.05° C. and the chamber usually operated within a range of ±0.25° F. Thermograph records made on a cylinder operated by a 29-hour clock formed perfectly straight lines. Circulation of the air-gas mixture was, at first, provided by a conventional fan but since this did not give sufficient circulation in a fully loaded chamber, it was replaced with a centrifugal blower. A 1-pound applicator[2] with a 100 ml. graduated cylinder was used for measuring and introducing the methyl bromide. The liquid was allowed to run into a copper pan placed on top of the heater. The door, walls, and conduit entrances of the chamber were checked for leaks with a *Frigidaire* leak detector.

METHODS AND PROCEDURE.—Many tests in which both tea scale and camellia scale were used showed that there was no practical difference in the resistance of the two species to methyl bromide. Tea scale was used in most of the experiments because of its abundance and lower natural mortality.

In addition to an infested camellia with sufficient scale to provide a count, at least three known varieties of camellia and one of azalea were used in each test for plant injury records. In each series of tests, temperature and dosage were held constant and the exposure varied. The exposure increment was usually 0.5 hour but shorter and longer intervals were used as needed. At each given temperature and dosage, five or more exposures were necessary to determine the requirements for a perfect kill of the insects and to establish plant tolerance. When uncertain results were obtained, the tests were repeated. Obviously, the threshold of plant injury could not be established with the same accuracy as the requirement for perfect insect kills.

The floor of the chamber was sprinkled with water to maintain high humidity, before introducing the plants. The chamber was allowed to warm up gradually to the desired temperature and this temperature was maintained by the heater before the gas was introduced. The dosage was calculated for the cubic contents of the chamber with no allowance for the space occupied by the load. Although the chamber was provided with a cooling coil, practically all of the results reported herein were obtained when outside atmospheric temperatures were such that fumigation could be done without its use. Thus, fumigation at temperatures of 60 and 70° F. was carried out in the winter while fumigation at higher temperatures was carried out in the summer.

The plants were placed in the shade after fumigation, and injury notes were made at frequent intervals. In the summer at least six weeks were allowed to pass before making scale counts. In the winter,

Table 1.—Exposures required for a complete kill of the scale insects on camellias, and the exposure limits of azaleas and camellias with several concentrations of methyl bromide at different temperatures.

TEMPERATURE °F.	DOSAGE Lbs./1000 Cu. Ft.	EXPOSURES IN HOURS		
			Limits for	
		To Kill	Azalea	Camellia
60	1.5	4.5	—	—
	2.0	3.5	7.0	8.0
	3.0	2.25	3.5	5.0
	4.0	1.75	3.0	3.5
70	0.5	9.0	—	—
	1.0	4.5	7.0	8.0
	2.0	2.5	4.5	5.0
	2.5	2.0	—	—
	3.0	1.5	3.0	4.0
	4.0	1.25	2.0	2.5
80	0.5	7.0	14.0	14.0
	1.0	3.5	6.0	7.0
	2.0	2.0	3.0	3.5
	3.0	1.25	2.5	3.0
	4.0	1.0	1.0	1.0
90	0.5	5.0	10.0	10.0
	1.0	2.5	3.5	4.0
	2.0	1.25	2.0	2.5
100	0.5	4.0	6.0	6.0
	1.0	2.0	2.5	3.0
	2.0	1.0	1.5	1.5
110	0.5	3.0	3.0	3.0
	1.0	1.5	1.5	2.0
	1.5	1.0	—	—

[1] *Quickset* bimetallic thermoregulator supplied by the American Instrument Company.
[2] Supplied by Arrow Products Company.

however, the decomposition of the scales and eggs was so slow that it was necessary to hold the plants for three or four months before reliable counts could be made. Only female scales and their eggs were examined. The term "perfect kill" means that there was no survival of these stages. In a series of counts where there were imperfect kills, no more than 500 scales were examined from each plant. To establish a perfect kill, from 500 to 1000 scales were examined, depending on how near a perfect kill was obtained in a preceding test.

THE RELATIONSHIP OF TEMPERATURE, DOSAGE, AND EXPOSURE.—The results of experiments with dosages of 0.5, 1, 2, 3, and 4 pounds per 1000 cubic feet at various temperatures are given in table 1. With any given dosage it is readily seen that the margin of plant safety decreases as the temperature increases. A temperature of 110° F. appears to be critical, i.e., the requirement for a perfect kill is essentially the maximum that the plants will stand without injury. There is sufficient margin of safety to fumigate at 100° F. with dosages of 0.5 and 1 pound,

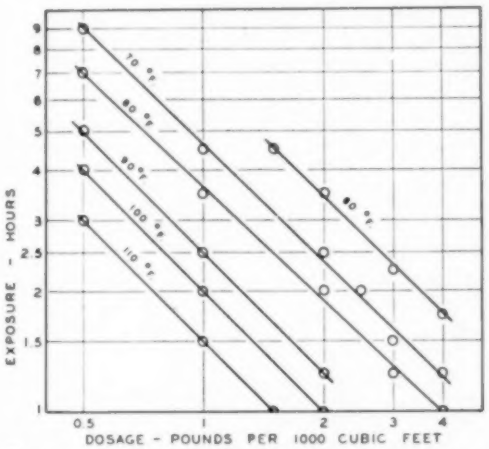

FIG. 1.—Data on the requirements for a perfect insect kill at various temperatures. Exposure plotted against dosage on logarithmic scales.

and at 90° F. with a dosage of 2 pounds. At lower temperatures larger dosages may be safely used. Ordinarily, camellias will stand from 0.5 to 1 hour longer exposures than azaleas at a given temperature and dosage.

In a systematic piece of work, Hamilton (1941) concluded that the requirement for a kill of the common red spider, *Tetranychus telarius* (L.), was essentially a product of the dosage and exposure at any given temperature. This implies that dosage in pounds per 1000 cubic feet is equivalent to exposure in hours. In the work on scale insects on camellias this relationship was found to be essentially true.

Table 2.—The relationship between dosages of methyl bromide and exposures at various temperatures.

TEMPERATURE °F.	EQUATION[1]
60	$DE=6.91$
70	$D^{0.97}E=4.66$
80	$D^{0.98}E=3.65$
90	$DE=2.50$
100	$DE=2.00$
110	$DE=1.50$

[1] D = Dosage in pounds per 1000 cubic feet; E = Exposure in hours.

When exposure was plotted against dosage on logarithmic paper the points fell approximately along straight lines (Fig. 1). The equations of these lines are given in table 2, and it will be observed that the exponent of D (dosage) is 1, except for the 70 and 80° F. lines, and the exponent of D in these two equations is so near 1 that it has been accepted as correct in order to simplify the relationship of dosage, exposure, and temperature. When DE (dosage×exposure) was plotted against temperature on semi-logarithmic paper, the points fell approximately along a straight line (Fig. 2), and the equation of this line is $DE=40.23e^{-0.030T}$, where D is dosage in pounds per 1000 cubic feet, E is exposure in hours, and T is temperature in degrees F. The nomograph (Fig. 3-I) may be used for approximating the relationship of the dosage, exposure, and temperature requirements necessary for a perfect kill of the scale insects on camellias.

The data which define the tolerance limits of azalea and camellia were too irregular to plot a group of curves as was done with the data on insect kill. However, by using the mean DE constant for each temperature the data plot approximately to straight lines on semi-logarithmic paper over a temperature range of 60 to 100° F. (Fig. 2). The equation which defines the tolerance limit of azalea is $DE=106.4e^{-0.0361T}$, and that defining the tolerance limit of camellias is $DE=159.8e^{-0.0396T}$. A nomograph (Fig. 3-II) may also be used for approximating the relationship of these data.

PLANT INJURY STUDIES.—Methyl bromide injury to camellias is of three types: partial or complete defoliation without burning, caused by excessive dosages or fumigation for excessive periods of time; development of dark areas on the leaves from which plants usually recover without defoliation; and acute burning of both new and old foliage. Burning of new foliage may occur on plants even though protected from the sun after fumigation, but if the plants are large such injury is of no consequence. Small plants, half or more of which is tender growth, may be seriously injured or killed. Burning of old foliage rarely occurs if the plants are shaded immediately after fumigation.

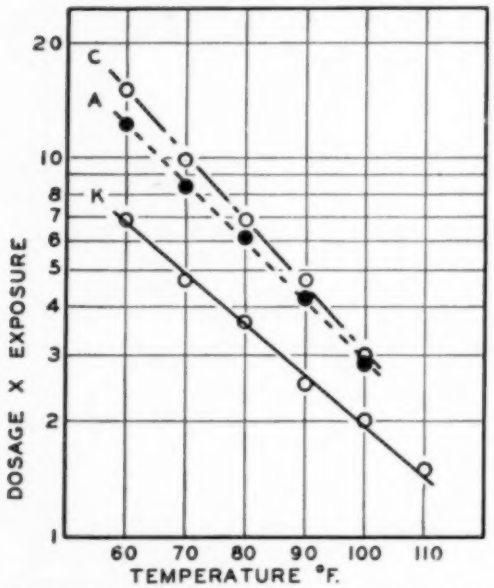

FIG. 2.—The variation of the dosage-exposure product with temperature; for a perfect insect kill, K; limits of safety for camellia, C, and for azalea, A.

Since early experiments indicated that plants must be protected from sunlight after fumigation to avoid injury, tests were conducted to determine the length of time such protection was necessary. Four lots of plants, each containing three varieties of camellias and one of azalea, were fumigated with 2 pounds for 2 hours at 80° F. in cool October weather. One lot was placed in the sun immediately after fumigation and the others were placed in the sun 1, 2, and 4 days later. The lot placed in the sun immediately after fumigation was severely burned; the others were not injured. A similar experiment was conducted in the summer when maximum atmospheric temperatures approximated 90° F. The plants were fumigated with 2 pounds for 1.5 hours at 90° F. Those placed in the sun immediately after fumigation were severely burned. Untreated plants placed in the sun at the same time showed no injury. Fumigated lots placed in the sun 4 and 24 hours later showed slight injury, whereas plants kept in the shade for two days were not injured. It is evident from these experiments that plants must be kept in the shade after fumigation for at least 24 hours and preferably 48 hours. In a commercial test one lot of plants, which was planted outside immediately after fumigation during cloudy weather in the winter, was injured, while a part of the same lot which was planted in the lath house at the same time was not injured. Spraying fumigated plants with water did not prevent injury to plants placed in the sun.

No systematic study was made of the effect of humidity in the chamber during fumigation. However, in a series of summer tests it was necessary to operate the cooling coil in order to maintain a temperature of 70° F. In this case the differential between a perfect insect kill and plant injury was less than at 80° and at 90° F. Since subsequent tests showed the margin of safety to increase with decreasing temperature, the indications are that the moisture precipitated by the cooling coil may reduce the humidity sufficiently to lower the margin of safety.

No plant injury resulted from the continuous operation of blowers with excessive capacity throughout the fumigation period, but plants should be protected from the direct radiation of heating units.

In order to determine varietal resistance to injury, ten plants of each of 44 varieties of *Camellia japonica* and 9 of *C. sasanqua* ranging in size from 10 to 15 inches were dug from cold frames and placed in open crates with the moist soil adhering to the roots of the plants. After fumigation with a dosage of 2 pounds per 1000 cubic feet for 2 hours at a temperature of 80° F., they were planted in the lath house. As the weather was warm and the sun bright, the plants were shaded with burlap in addition to the lath. There was no injury of consequence, but some of the plants with delicate new growth were slightly burned.

Two plants each of 79 varieties of azaleas ranging in size from 12 to 24 inches and including representatives of the Indica and Kurume groups, were dug from the lath house and fumigated "as dug" without burlap on the soil ball, using 2 pounds per 1000 cubic feet for 2 hours at 80° F. The only varieties injured were Coral Bell and Salmon Beauty which exhibit a peculiar susceptibility to methyl bromide, and were killed.

their roots. These plants usually had a varying infestation of camellia scale, but to obtain a positive check on the kill of scale, larger plants infested with tea scale were placed at various locations in the chamber. Some survival of scale was obtained with a schedule of 2 pounds for 2 hours at 80° F. The dosage was raised to 2.5 pounds at the same temperature and exposure, but still there was slight survival. The difficulty was finally overcome

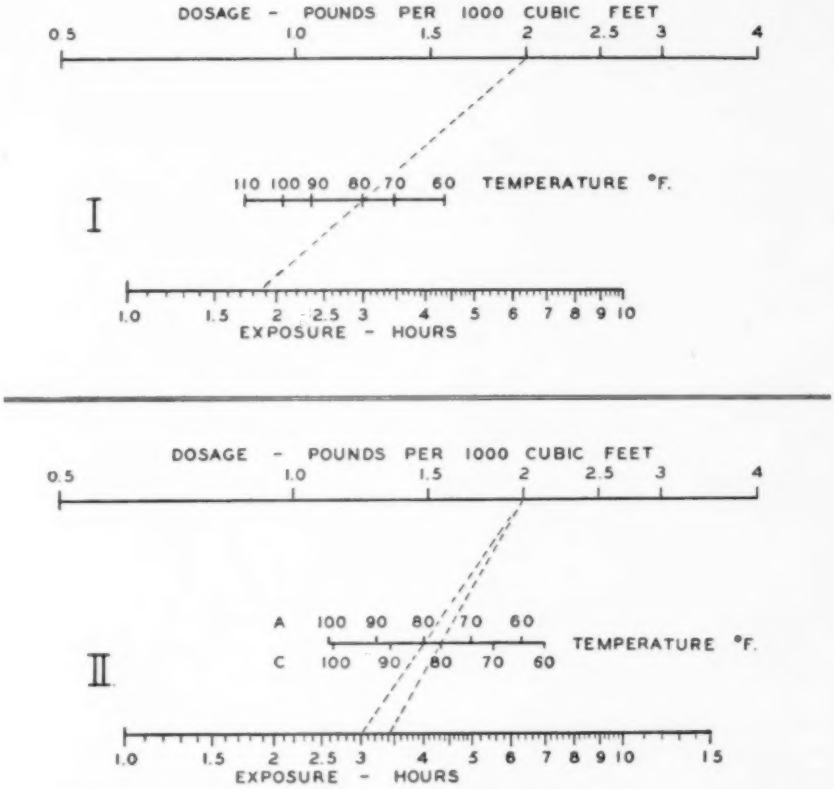
DOSAGE - POUNDS PER 1000 CUBIC FEET
0.5 1.0 1.5 2 2.5 3 4
I
110 100 90 80 70 60 TEMPERATURE °F.
1.0 1.5 2 2.5 3 4 5 6 7 8 9 10
EXPOSURE - HOURS
DOSAGE - POUNDS PER 1000 CUBIC FEET
0.5 1.0 1.5 2 2.5 3 4
II
A 100 90 80 70 60
C 100 90 80 70 60
TEMPERATURE °F.
1.0 1.5 2 2.5 3 4 5 6 7 8 9 10 15
EXPOSURE - HOURS

FIG. 3.—I. Nomograph for obtaining the relationship of the dosage, exposure, and temperature requirements for a perfect kill of the scale insects on camellia. II. Nomograph for estimating the plant tolerance limits. Use scale C for camellia and A for azalea.

COMMERCIAL FUMIGATION.—Experiments with the chamber loaded to capacity were conducted in a 200-cubic foot chamber essentially of the same construction as the one used for the detailed tests. In addition to the floor space, this chamber was equipped with three removable decks which permitted loading of small plants to the top.

Plants 10 to 15 inches high were dug from cold frames and placed in flats or open crates with moist soil adhering to

by working out a pre-heating schedule that would insure a uniform temperature of the load.

Studies were made of temperatures inside the chamber by placing the active element of a soil thermograph in a crate of plants on the bottom floor. Later, in another chamber, a *Fenwal*[1] thermoswitch on the end of a flexible conduit was used in the bottom of the load for similar studies. This switch was adjusted to turn off a

[1] Obtained from Fenwal Incorporated.

light on the outside of the chamber when the desired temperature had been approximated. With this equipment the following successful procedure was worked out: After loading, both heating units were operated until the air temperature was at least 5 degrees higher than the temperature desired for fumigation. Then the manually controlled heater was turned off. One hour later the gas was introduced. In the meantime the air temperature would gradually fall until the scheduled temperature was reached, and this was maintained by the heating unit operated by the thermostat. The blower was allowed to run throughout the entire period of pre-heating and fumigation.

Table 3.—Results of fumigating tea scale with methyl bromide in a fully loaded chamber.

Temperature °F.	Dosage Lbs./1000 Cu. Ft.	Exposure in Hours	Per Cent Dead Scale on Plants[1] A	B	C	D
60	3	2½	90.8	98.6	99.8	99.4
60	3	3	100.0	100.0	100.0	100.0
70	2	3½	100.0	100.0	100.0	100.0
70	2	3½	100.0	100.0	100.0	100.0[2]
70	2½	2½	95.0	100.0	100.0	100.0
70	2½	3	100.0	100.0	100.0	100.0
80	2	2½	100.0	100.0	100.0	100.0[2]
80	2	2½	100.0	100.0	100.0	100.0[2]
80	2½	2	100.0	100.0	100.0	100.0

[1] Location of plants: A, bottom floor N. E. corner; B, bottom floor center; C, second floor center; D, bottom floor S. W. corner. One thousand scales were examined from each plant. Tests the previous season showed that scale survival was always highest on the bottom floor.

[2] Counts of over 1000 *L. camelliae* from widely distributed samples of these loads showed no survival. There was insufficient material on the other loads to make counts of this species.

During the winter of 1941–42 a series of tests, using the above procedure, was made with fully loaded chambers to establish satisfactory commercial fumigation schedules (Table 3). From these data the following schedules are recommended: At 60° F., 3 pounds for 3 hours; at 70° F., 2 pounds for 3.5 hours; and at 80° F., 2 pounds for 2.5 hours. Sufficient tests have been run to indicate that for summer fumigation a schedule of 2 pounds for 1.5 hours at 90° F. will be reliable provided atmospheric temperatures are not much below 90°. It will be observed that these schedules call for an exposure of about 0.5 hour longer than was found necessary in experiments with small loads (Table 1). In using the nomograph (Fig. 3-I) for estimating commercial schedules, it appears that a conservative rule would be to increase the exposure period about 25 per cent at a given dosage and temperature. It is quite likely that for fumigation in small chambers and with adequate preheating the theoretical schedules would be found dependable.

During the 1941–42 season, 33 lots of camellias (mostly in full chambers) were fumigated for nurserymen at schedules of 2 pounds for 2.5 hours at 80° F. and 2 pounds for 3.5 hours at 70° F. A definite check was made at destination on 19 lots and there was no survival of scale. Included were 143 varieties, many of them rare and expensive. So far as could be determined there was no loss of plants except one lot of small plants with excessive new growth which was fumigated in the late spring.

Fumigation of Camellias under a Wet Canvas.—The plants were growing in cold frames 6 by 24 feet having an average depth of 1 foot. The frames were covered with a piece of 7-ounce army duck large enough to lie flat on the ground around the frame. Near the center a thermometer was fitted into a grommet in the canvas with a cork. A 4-inch fan was operated by the truck battery throughout the fumigation period. The canvas was wet thoroughly before introducing the gas and at 15 minute intervals thereafter to control the temperature and reduce leakage of gas. The selected dosage was measured in a graduated cylinder and poured into a pan under the canvas.

A dosage of 3 pounds per 1000 cubic feet with exposures of 1.33 hours at 86–88° F. and 1.66 hours at 83–85° F. failed to give a perfect kill of *Lepidosaphes camelliae* Hoke. A dosage of 4 pounds for 1.5 hours at 85–88° F. gave a perfect kill, but caused slight damage to tips of the plants. This proved to be of no practical consequence, and, according to the nurseryman, when the next flush of growth occurred they were of more desirable shape than the unfumigated plants.

With two or three canvases, enough to keep a crew of two men busy, this method might prove to be practical. However, since camellias are dug from the coldframes either for sale or for transplanting, they could be loaded into a chamber and fumigated without uncertain results and with very little, if any, difference in final cost.

EXPERIMENTS WITH MISCELLANEOUS PESTS.—From time to time opportunities occurred for testing the effectiveness of methyl bromide on several other pests. A schedule of 2 pounds per 1000 cubic feet for 2 hours at 80° F. gave perfect kills of the red mite, *Paratetranychus ilicis* McG., on camellias; and the azalea mealybug, *Eriococcus azaleae* Comst., on azalea. A dosage of 2 pounds for 1.5 hours at 80° F. and for 1 hour at 90° F. gave perfect kills of azalea lacebug, *Stephanitis pyrioides* Scott, including the eggs in the leaf tissue of azaleas. A dosage of 2 pounds for 1.5 hours at 90° F. was required to kill all stages of the greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché), on azalea foliage.

SUMMARY.—The effectiveness of methyl bromide against *L. camelliae* Hoke and *F. theae* Green was studied over a temperature range of 60 to 110° F. and with dosages ranging from 0.5 to 4 pounds per 1000 cubic feet in gas-tight chambers. The relationship between the dosage and exposure requirements for a perfect kill of these scale insects was found to be logarithmic at constant temperature, and the relationship is approximated by the equation $DE=C$, where D is the dosage in pounds per 1000 cubic feet, E is the exposure in hours, and C is a constant. Furthermore, DE was found to be an exponential function of temperature, and the relationship is approximated by the equation $DE=40.23e^{-0.030T}$, where T is temperature in degrees F. A nomograph was designed for obtaining the relationship of the three variables.

The margin between the requirements for a perfect kill of the scale insects and injury to the host decreased as the fumigation temperature increased. This margin of safety was sufficient to permit practical fumigation of camellias and azaleas at any desired temperature from 60 to 100° F., provided the plants were shaded for at least 24 hours after fumigation. The plant tolerance limits were also approximated by exponential equations and a nomograph was designed for estimating these limits.

Of the many varieties of camellias that were fumigated none was found to be particularly susceptible to methyl bromide. Two varieties of azaleas, Coral Bell and Salmon Beauty, out of 79 tested apparently cannot be fumigated. Fumigation schedules and a procedure for the commercial treatment of plants were developed. Recommended schedules are 3 pounds per 1000 cubic feet for 3 hours at 60° F., 2 pounds for 3.5 hours at 70° F., 2 pounds for 2.5 hours at 80° F., and 2 pounds for 1.5 hours at 90° F.[1]—6-1-43.

[1] ACKNOWLEDGEMENTS.—The author is indebted to Mr. G. F. Turnipseed, of the State Department of Agriculture, for assistance in carrying out the experiments and making counts of scale insects; to the nurserymen of Mobile County for supplying plants and facilities for the experiments; and to Dr. C. F. W. Muesebeck and his staff of the U. S. Bureau of Entomology and Plant Quarantine for the identification of pests. The author also appreciates the suggestions and cooperation of Dr. Lon A. Hawkins of the U. S. Bureau of Entomology and Plant Quarantine, Dr. D. B. Mackie and Mr. Harold J. Ryan of the California Department of Agriculture.

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Comparative Susceptibility of Two Strains of California Red Scale to HCN, with Special Reference to the Inheritance of Resistance

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As early as 1912, according to Quayle (1938a), citrus growers in the vicinity of Corona, Calif., began to obtain unsatisfactory results from fumigation of the California red scale, *Aonidiella aurantii* (Mask.), with hydrocyanic acid. From 1915 to 1922 Quayle (1922) fumigated scale-infested fruit from this and other localities simultaneously, and he found the red scale from Corona to be especially resistant. In more recent tests Quayle (1938b) shows that the scale from certain areas are more difficult to kill than those from certain other areas. Woglum (1925) reported that entirely satisfactory control of the California red scale in the Corona area was not obtained in 1918 with twice the dosage that thoroughly controlled the insect there in 1907 to 1909. In certain other localities the scale was controlled with fumigation almost as easily in 1924 as it had been 15 years previously. Gray & Kirkpatrick (1929), Moore (1936), and others[1] have also observed a difference in the susceptibility of scales from different localities.

A study of two strains that were found to differ in their susceptibility to hydrocyanic acid gas has been carried on at Whittier, Calif., since 1934,[2] with special attention to the comparative susceptibility, the inheritance of resistance, and the stability of the strains when exposed to repeated fumigations.

METHODS AND MATERIALS.—Scales that were specially resistant were found in the Wellman-Parson grove near Corona, and scales that were specially nonresistant in the McKenzie grove near Escondido, Calif. To eliminate the possibility that the difference in susceptibility might be due to differences in climatic conditions during development, scales from the two groves were brought to Whittier in May 1935 and placed in adjacent insect-tight compartments in the insectary, where they were reared on young lemon trees growing in pots. After the population on the potted trees had built up for two years, infestations of both strains of these scales were started on lemon fruits from the field, the fruits infested with each strain being held in separate rooms in an isolation house. Although the two strains were propagated in their respective isolation rooms under conditions similar to those outdoors, the insects to be used in laboratory tests were reared on lemon fruits in the laboratory at a constant temperature of 77° F. and a constant relative humidity of 65 per cent, unless otherwise stated. Since the infestations were made simultaneously, the scales of the stocks being compared were of the same age, and were in the same stage of development at the time of fumigation. The population density on the host lemons was as nearly as possible the same for each stock.

The procedure and the laboratory apparatus used in the fumigation were the same as those described by Yust *et al.* (1942). Unless otherwise stated, the scales were exposed to a constant concentration of hydrocyanic acid for 40 minutes at a temperature of 77° F. and a relative humidity of 65 per cent, and each mortality record was based on 1,200 insects on 24 lemon fruits with no corrections for natural mortality. The data were analyzed by statistical methods.

Crossing of the two strains was demonstrated by the occurrence of reproduction after males of each strain had been placed in sealed capsules with unfertilized females of the opposite strain. Mass crosses were made by removing all the males from lemons infested with given stocks of scales as soon as the sexes were distinguishable and subsequently placing the males and females of the desired stocks together in isolation cages.

Repeated fumigations were applied to several stocks, each of which was propagated with the offspring of survivors of the preceding fumigation. The fumigations were made against successive or

[1] Unpublished data at the Whittier, Calif., laboratory of the Bureau of Entomology and Plant Quarantine.

[2] The study was begun by the late F. S. Stickney and carried on by him until his death in the summer of 1936.

alternate generations, and while the scales were in the second molt. These stocks were divided into two groups, one of which was fumigated repeatedly and the other was propagated without fumigation. Usually two infestations of each group were made for each generation, one for propagation and the other for test purposes. By this procedure it was possible to determine the relative susceptibility of scales with and without a history of repeated fumigation. The group given repeated fumigations was treated with concentrations of hydrocyanic acid usually giving from 50 to 75 per cent mortality.

Other fumigation tests on different generations of scales in the same stages have been made on many occasions since 1938. In each test the nonresistant strain showed a much higher mortality than the resistant strain, and in general the difference was greatest between scales in the second molt. The mortality of scales in the second molt averaged 99.3 per cent for the

Table 1.—Mortality of the resistant and nonresistant strains of the California red scale from hydrocyanic acid fumigation when the scales were taken from lemon groves and when reared on potted lemon trees in the insectary for approximately 1 year.

Date of Fumigation	Source and Location of Scales	Temperature	Relative Humidity	Concentration of Gas	Scales Included in Test[1]		Mortality[2]	
					Resistant	Nonresistant	Resistant Strain	Nonresistant Strain
		°F.	*Per cent*	*Mg. per liter*	*Number*	*Number*	*Per cent*	*Per cent*
May 17, 1935	Field-infested fruits	77	62	0.56	178	142	15.6±0.8	95.1±2.2
June 10, 1936	Insectary-infested leaves and twigs	86	34	0.58	269	158	57.6±4.6	96.8±2.1

[1] Numbers on 2 lemons and on 1 tree.
[2] Corrected for natural mortality.

COMPARATIVE SUSCEPTIBILITY.—The scales from Corona and those from Escondido were tested for susceptibility when they were brought to the laboratory and again after the stocks had been maintained in the insectary for about a year. In the first tests the scales were fumigated on the lemon fruits on which they had developed in the respective groves, and in the later tests the scales were on potted lemon trees that had been infested in the insectary. In each case the two strains were fumigated simultaneously. The effectiveness of the treatment was based on the mortality of the female insects in the second molt and in the gray adult and mature stages. The results are shown in table 1.

In both tests the two strains differed greatly in susceptibility. The mortality of the nonresistant strain was similar in both years, but that of the resistant strain was much higher in 1936. The tree infested with the resistant scales in the insectary may have been in an inferior condition owing to the heavy infestation, for experiments by Yust & Howard (1942) have shown higher mortalities on inferior lemon fruits.

nonresistant strain and 32.5 per cent for the resistant strain, as compared with 98.9 and 60.3 per cent, respectively, for the mature females. Although the differences varied considerably on different dates, no consistent increase or decrease was evident.

The difference in the susceptibility of the two strains was not the result of differential growth rates, for no such differences have been found. Furthermore, although female scales of different ages in the same stage showed a marked difference in mortality in the two strains, as is evident from the data in table 2, the scales of the nonresistant strain were more susceptible to fumigation than those of the resistant strain regardless of age.

A marked difference between strains also existed in populations of younger stages that included both males and females before sex differentiation became evident, as well as in populations of male

Table 2.—Mortality of female scales of the two strains of the California red scale fumigated at different ages in the second molt and in the mature stage.

Scales in Second Molt			Mature Scales		
	Mortality[1]			Mortality[1]	
Age	Resistant	Nonresistant	Age	Resistant	Nonresistant
Days	*Per cent*	*Per cent*	*Days*	*Per cent*	*Per cent*
19	13.7	100	35	43.2	98.7
20	16.0	98.5	36	55.0	99.2
21	39.2	99.2	37	41.2	98.5

[1] Each record is based on 400 scales.

scales in the later stages. That the permeability of the wax covering was not a factor was shown by two kinds of tests. When new settlers were treated before their coverings had been formed, there was a marked difference between resistant and nonresistant strains. In other tests, in which the coverings were lifted from scales in the late gray adult stage before treatment, the differences between strains remained although the kills were higher.

In most of the tests at the laboratory the insects were fumigated with constant concentrations of the gas. In commercial field fumigations, on the other hand, the concentration attains its maximum shortly after the cyanide charge is introduced under the trees and then decreases to a low point at the end of the exposure. This change in concentration may be expressed by a curve which is frequently referred to as a decreasing-type concentration curve. In several laboratory fumigations in which the two strains were treated simultaneously with decreasing concentrations of hydrocyanic acid, such as would be represented by a decreasing-type curve, there was also a marked difference in mortality.

In another experiment the two strains were reared under fluctuating temperatures and humidities. Scales reared simultaneously in a lath house under outdoor conditions and fumigated with a decreasing concentration of gas at 59° F. still showed a marked difference in the mortality of the two strains.

Susceptibility of Hybrids.—Since the difference in susceptibility to hydrocyanic acid fumigation appeared to depend on inherent differences in the insects themselves, in 1938 the susceptibility of offspring of reciprocal crosses of the two strains was studied. Female scales in each of five generations of each strain and cross were fumigated when in the second molt and in the mature stage, two fumigations being made of scales in the F_2 generation. Prepupal and pupal males of the F_1 generation were also fumigated. The results are presented in table 3. The mortalities following fumigation of these stages in the F_1 generation, of female scales in the F_2

Table 3.—Mortality from hydrocyanic acid fumigation of the resistant and nonresistant strains of the California red scale and of reciprocal crosses of the two strains in each of five generations.

Generation	Age	Concentration of Gas	Mortality			
			Resistant	Resistant Female × Nonresistant Male	Nonresistant Female × Resistant Male	Nonresistant
	Days	*Mg. per liter*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
			Females in second molt			
F_1	20, 21	0.58	50.6	63.8	69.5	99.5
F_2	20	0.58	31.4	35.0	82.2	99.2
F_2	19, 20, 21	0.58	23.0	42.5	83.4	99.2
F_3	20, 21	0.58	50.6	69.4	84.3	99.5
F_4	20	0.58	31.4	49.9	80.8	99.2
F_5	20	0.58	23.8	48.4	72.7	98.7
			Mature females			
F_1	35, 36	0.49	73.6	81.2	82.2	99.8
F_2	36	0.47	64.6	68.3	85.9	99.2
F_2	35, 36, 37	0.47	46.3	49.7	84.1	98.8
F_3	35, 36	0.49	73.6	83.6	89.3	99.8
F_4	36	0.47	64.6	70.5	83.8	99.2
F_5	35	0.46	66.3	64.1	81.0	97.9
			Males in prepupal and pupal stages			
F_1	20, 21	0.58	78.8	81.2	98.9	98.8

generation, and of female scales of certain other crosses and recrosses obtained at the same time as those of the F_2 generation are shown in figure 1.

The mortalities of both female stages in the F_1 generation of hybrids were greater than those of the resistant strain but more like those of the resistant than of the nonresistant strain. Resistance therefore appears to be incompletely dominant. The males in the F_1 generation are like the mother parent, either resistant or nonresistant, suggesting that the gene for resistance is in the sex chromosome (Sinnott & Dunn 1939). In general these conclusions correspond to those reached by Dickson (1941).

When the males of the resistant female ×nonresistant male cross (theoretically resistant) were backcrossed with females of the resistant strain, the mortality of the female progeny was not significantly different from that of the resistant strain. Conversely, when the males of the nonresistant female×resistant male cross (theoretically nonresistant) were backcrossed with females of the nonresistant strain, the mortality of the female progeny was not significantly different from that of the nonresistant strain. Here is further evidence that the F_1 generation males of reciprocal crosses are like the mother parent. Female progeny of reciprocal recrosses of the F_1 generation of reciprocal crosses showed mortalities similar to those of the F_2 generation of the original crosses (permitted to self) with the same theoretical inheritance. These results also were expected on the assumption that the gene for resistance is a sex-linked character.

After the F_1 generation (table 3) the mortality of the nonresistant female×resistant male hybrids was always greater than that of the resistant female×nonresistant male hybrids. In most cases the mortality of the latter hybrids was greater than that of the resistant strain, as would be expected if resistance was incompletely dominant, but in several tests the differences were not statistically significant.

EFFECT OF REPEATED FUMIGATIONS.—To determine the effect of exposure to repeated fumigations, five stocks of scales were selected, (1) the resistant strain, (2) the nonresistant strain, (3) a mixture obtained by infesting lemons with approximately equal numbers of scales of both strains, (4) a stock started by propagating the offspring of scales that survived fumigation of the third generation of the mixture, herein referred to as the "survivors of the mixture," and (5) a stock started by propagating the offspring of scales that survived fumigation of the resistant strain, referred to as the "survivors of the resistant strain." The results of tests applied to the progeny of the survivors of each of three fumigations are shown in table 4.

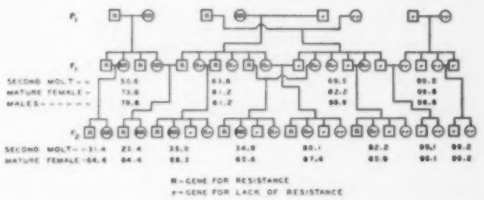

FIG. 1.—Diagram of the inheritance of resistance to hydrocyanic acid fumigation by the California red scale suggested by the mortality of the resistant and nonresistant strains and of the indicated crosses of the two strains. The mortality of female scales in the second molt and in the mature stage is indicated for the F_1 and F_2 generations and of males in the F_1 generation. (Squares indicate males, circles females.)

After one fumigation the mortality of the offspring of the survivors of the resistant strain was not significantly different from that of the resistant strain, but after two and three fumigations the progeny of this stock were significantly more difficult to kill both in the second molt and in the mature stage.

In both stages the mortality in the mixture that originally contained both resistant and nonresistant scales was between that of the pure strains. This stock was discontinued after the second test, since it was made against the seventh generation of the mixture and the two tests suggested that the relative susceptibility of this stock would remain the same.

After one fumigation the offspring of the survivors of the mixture were much less susceptible than scales in the original mixture, suggesting that a considerable proportion of the nonresistant scales were eliminated from the population by one fumigation in the laboratory. After the first two fumigations this stock was not significantly more resistant than the resistant strain, but after three fumigations it was significantly more resistant than the resistant strain in both the second molt and the mature female stage. Al-

Table 4.—Mortality of several stocks of the California red scale after each of three fumigations with hydrocyanic acid.

Fumigation No.	Gas Mg. per Liter	Per Cent Mortality				
		Resistant Strain	Survivors of Resistant Strain	Mixture	Survivors of Mixture	Nonresistant Strain
		Females in second molt				
1	0.58	50.6	43.1	70.8	46.0	99.5
2	0.58	23.8	17.4	60.0	26.5	98.7
3	0.58	42.8	32.6	—	31.4	99.6
		Mature females				
1	0.49	73.6	71.6	84.4	74.7	99.8
2	0.46	66.3	51.1	74.5	60.9	97.9
3	0.47	55.2	46.8	—	48.1	98.2

though the kills in the repeated fumigations were relatively low, the fumigations were very effective in eliminating nonresistant scales, probably because the treatments were made before the females were fertilized. The surviving females could then mate only with males that had survived a treatment.

Additional stocks bred from reciprocal crosses of the two strains were fumigated when in the F_2 generation, and both stocks were given a second fumigation in the F_3 generation. Survivors in the second molt and in the mature female stage of the F_4 generation were tested, respectively, with concentrations of 0.58 and 0.47 mg. of hydrocyanic acid gas per liter. The resulting mortalities in comparison with those of the resistant strain are shown in table 5. In three cases out of four the progeny of the reciprocal crosses were significantly more difficult to kill than scales in corresponding stages of the resistant strain.

MIXED STRAINS IN ORIGINAL STOCKS.—It was expected that a stock composed of a mixture of resistant and nonresistant scales would become increasingly more resistant to hydrocyanic acid as the nonresistant scales were eliminated by repeated fumigation. Since the survivors of this stock became even more resistant than those of the resistant strain, it appeared that nonresistant scales must have been present in the so-called resistant strain. Similar indications were previously obtained in preliminary work.

Table 5.—Mortality of survivors of the resistant strain and of reciprocal crosses of the resistant and nonresistant strains of the California red scale.

Stock	Per Cent Mortality	
	Scales in Second Molt	Mature Females
Resistant strain	31.4	64.4
Survivors of resistant female ×nonresistant male cross	24.0	53.5
Survivors of nonresistant female×resistant male cross	31.5	56.7

A group of nonresistant scales were fumigated in September 1939, beginning a stock referred to as "survivors of the nonresistant strain." The treatment gave a kill of 87.1 per cent, reducing the population to such a low point that three generations were required to build it up sufficiently to infest lemons for test purposes. One test fumigation of this stock killed 87.5 per cent of the scales in the second molt and 77.7 per cent of mature females, in comparison with 98.7 and 97.9 per cent in the corresponding stages of the nonresistant strain. Since one fumigation markedly increased the resistance of the stock, it is probable that there were resistant scales in the so-called nonresistant stock.

It might be concluded that the possible mating of some nonresistant males with nonresistant females in the supposed crosses of the two strains would explain the higher mortalities in the F_1 generation of the hybrids (Table 3). Further reciprocal crosses were therefore made with scales of the nonresistant strain as maintained in the laboratory and the survivors of a stock subjected to repeated fumigations which was more resistant than the resistant strain as maintained in the

laboratory. This test was made on the theory that if scales homozygous for resistance were crossed with scales of the nonresistant strain there would be no nonresistant female progeny in the F_1 generation. When such progeny were fumigated both in the second molt and in the mature stage, both stages were significantly more susceptible than scales of the resistant strain, these results further indicating that resistance is incompletely dominant.

SUMMARY.—A study of strains of the California red scale, *Aonidiella aurantii* (Mask.), that differed in susceptibility to fumigation with hydrocyanic acid was begun in the summer of 1934. Scales differing widely in susceptibility obtained from two sources were placed in adjacent isolated compartments in the insectary at Whittier, Calif., where they were reared on potted lemon trees for the duration of this study.

Throughout a period of more than six years there was a consistently higher kill of the nonresistant strain than of the resistant strain when the two strains were fumigated simultaneously. A difference in mortality occurred in each of the developmental stages tested and in both sexes. There was no evidence that the difference in susceptibility between the two strains had either increased or decreased over this period of time.

The difference in susceptibility between the two strains was not due to permeability of the wax covering, although removal of the scale covering prior to fumigation increased the kill.

Five generations of the hybrid stocks obtained from reciprocal crosses of the resistant and nonresistant strains were fumigated and the mortality was compared with that resulting from fumigation of the corresponding generation of the resistant and nonresistant strains. In the F_1 generation of the reciprocal crosses the males were like the mother parent with regard to susceptibility, suggesting that the gene for resistance is a sex-linked character, but the females were more like the resistant than the nonresistant strain, suggesting that resistance is incompletely dominant. Further crosses, recrosses, and backcrosses that were made verified these findings.

The data indicated that scales nonresistant to hydrocyanic acid fumigation were present in the resistant strain used in this study and that probably insects resistant to fumigation were also present in the nonresistant strain used. Repeated fumigations of successive generations of the resistant strain were followed by an increase in relative resistance to fumigation. Similarly, the susceptibility of the nonresistant strain was decreased somewhat by a single fumigation.—5-15-43.

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The Position of the Rostralis of the California Red Scale Feeding on Lemons

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The rostralis of the California red scale, *Aonidiella aurantii* (Mask.), is a long, delicate, threadlike structure, composed of modified mandibles and maxillae which are closely joined to form a narrow tube. Shortly after the young scale is born, the rostralis is inserted into the host tissue, from which food is drawn into the pharynx. The present studies were made to determine the position of the rostralis in the rind of lemon fruit and the injury to cells in which feeding occurs.

Method of Preparing Material.—Several portions of lemon rind containing scales in the first, second, and third stages were sectioned by the following method so that the rostralis could be traced from the point of insertion to its tip: A solution of chromo-acetic acid was used as a killing and fixing agent, after which the tissues were washed in tap water, dehydrated in increasing strengths of ethyl alcohol solutions, cleared in benzene, and embedded in filtered paraffin. Sections 10 microns in thickness were then cut with a rotary microtome, stained with Delafield's haematoxylin, and mounted in balsam.

Data Obtained by the Study.—Measurements of the rostralis of 10 insects in each stage showed the average lengths and diameters to be as follows:

Stage	Diameter in mm.	Length in mm.	Depth of Tip Below Surface, in mm.
First	0.0020	0.324	0.25
Second	.0024	1.037	0.61
Third	.0042	2.690	0.98

The majority of the crawlers settled in pits in the rind, and each inserted its rostralis near the bottom of the pit in which it had settled. The new rostralis of each stage was not inserted in the same spot as the one preceding, but to one side of it, or in some cases on the opposite side of the pit. The old rostralis of the preceding stage remained in the lemon rind.

The course followed by the rostralis of the first stage Fig. 1, I is more nearly perpendicular to the surface of the lemon rind than that of the longer rostralis of the second stage Fig. 1, II, or of the third stage Fig. 1, III. Only portions of the rostralis occurred in any one prepared section of rind.

Because of the differences in the paths of insertion, the depth of penetration was not always proportionate to the length of the rostralis in the respective stages. The

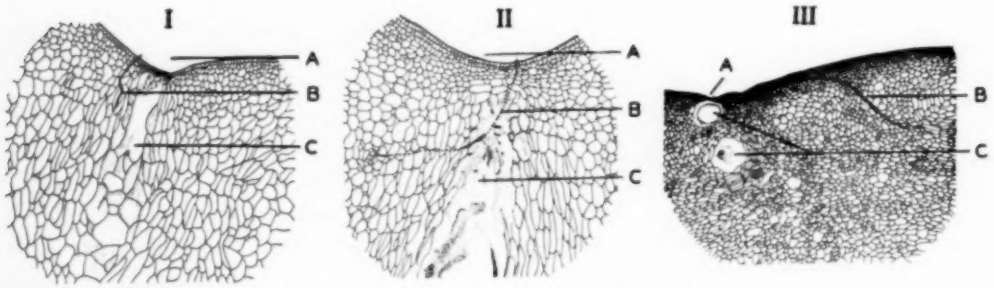

Fig. 1. I—Diagrammatic sketch of course of first stage rostralis through lemon rind, showing example of feeding near an oil vesicle (×150). A, Pit in rind; B, Rostralis; C, Oil vesicle.

II—Diagrammatic sketch of course of second stage rostralis through lemon rind (×150). Solid lines represent actual portions of rostralis in one section, dotted lines represent portions in subsequent sections. A, Pit in rind; B, Rostralis; C, Oil Vesicle.

III—Diagrammatic sketch of course of third stage (mature female) rostralis through lemon rind (×60). A, Pit in rind; B, Rostralis; C, Oil Vesicle.

average depth of penetration of the rostralis of the first stage was 0.25 mm., of the second 0.61 mm., and of the third 0.98 mm. Undoubtedly these averages would vary with a larger number of insects, but the above figures serve as a relative indication of what might prove to be the rule.

There was no indication that different insects in any one stage fed with the rostralis in the same position. In some cases the rostralis of the first stage terminated near the oil vesicle beneath the pit in which the insect had settled, and farther away in other instances. The second-stage insects always fed farther away from an oil vesicle than did those of the first stage. In the third stage feeding took place at a still greater distance from the oil vesicle over which the mouth parts were inserted, but the rostralis might approach an adjacent oil vesicle.

The tip of the rostralis was always located within a cell of the host tissue and it appeared that the scales secure most of their nourishment from that cell. There was no visible injury to the cells in which insects of the first stage were feeding, but cells in which scales of the second stage and of the third stage, or mature female, fed showed pronounced injury (Fig. 2). Many cells were penetrated by the rostralis as it was inserted into the lemon rind, but no injury was observed except that resulting from feeding.

SUMMARY.—This paper reports the results of a study of the position of the rostralis of various stages of the California red scale when feeding in the tissue of lemon fruit. It was observed that the average length of the rostralis increased appreciably with each stage of the insect and that scales of each stage fed at different levels in the rind. The path of the rostralis through the rind was found to be irregular. The tip of the rostralis was always located within a cell of the host tissue. There was marked injury to the cells in which second- and third-stage scales were feeding.—5-24-43.

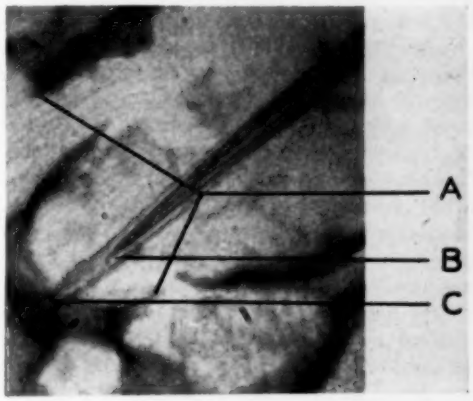

FIG. 2.—Tip of third stage rostralis (× 1425). A, Break in cell wall due to sectioning; B, Tip of rostralis; C, Apparent injury to cell.

Effect on Arsenical Deposits of Accessory Materials in the Spray Mixture[1]

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When lead arsenate is sprayed on apples for control of the codling moth, it is nearly always applied in mixtures with other materials. To save labor, the application is usually made in combination with a fungicide. Sometimes when a fungicide is not used, a safener is added to reduce the possible injury by water soluble arsenic. Often various other materials are added, presumably to improve the sticking and spreading properties of the spray mixture and thus increase the efficiency of the insecticide. While considerable attention has been given to the effect upon codling moth control of incorporation of spreaders in the spray mixture, the results are not in agreement. These differences in results have been reviewed recently by Graham & Richardson (1942).

Because of the uncertainty regarding the effect of these accessories in the spray mixture, a series of experiments were undertaken to measure by chemical analysis the amount of arsenic deposited upon leaf surfaces by spraying with lead arsenate alone, and in combination with various other materials. No attempt was

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made to measure either the relative durability of these various deposits or the effect of the accessory materials upon their relative insecticidal efficiency. This investigation is incomplete but the results are presented because, for the time being at least, it will not be continued.

The materials studied to determine their effect in the spray mixture upon the deposit of arsenic upon foliage included most materials used in spraying apples in Arkansas, which are as follows: fungicides including bordeaux mixture, wettable sulfur and lime-sulfur; hydrated lime, commonly added to reduce the possibility of arsenical injury to foliage; various adjuvants, including those most commonly used by fruit growers in Arkansas; and talc, which was added to the list to determine the effect of a presumably inert powder. The effect of oils and oil emulsions upon arsenical deposit was given relatively little attention. However, one white oil emulsion was included in the series of materials studied. As a rule, these materials were added to the spray mixture at the rate commonly used by fruit growers. The proprietary adjuvants were used at the rate directed by the manufacturers.

METHODS.—After a long series of unsatisfactory trials to secure uniform deposit by the use of glass slides and leaf surfaces, the primary leaves of one variety of bush lima beans were selected for the preliminary experiments in obtaining uniform deposit. The beans were grown in a greenhouse at an average temperature of 75° to 80° F. Six seeds were planted in each one-gallon earthenware jar and the seedlings were thinned to four plants in each jar so there was no overlapping of leaves. These were allowed to grow for two weeks or until the primary leaves were large enough to provide a suitable sample. At least 28 leaves in each replicate of each treatment were sprayed with the application made first from below and then from above. The soil in the jars was changed after being used twice in order to avoid a possible accumulation of arsenic which would affect the experimental work.

In all spraying experiments in the greenhouse, the foliage of the plants in each jar was sprayed with a pint atomizer. It was found that the heaviest deposit could be obtained if spraying stopped just before the run-off of the collected drops began and for this reason the aim was to continue spraying with each material up to this point. Three samples were taken for each application. To improve the uniformity of results, it was found best for all the spraying in a single series to be done by one man, for the differences in deposits resulting from spray applications by two individuals was often greater than the difference between the deposit from two different mixtures. All plants used for comparison in a single series were sprayed under as nearly identical conditions as possible and on the same day, since various changing environmental factors modified the amount of deposit. For instance, the deposit tended to be less on days of bright sunshine than it was on cloudy days.

After the spray deposit had dried thoroughly, the leaves were stripped from the plants and a sample of 100 square inches of leaf surface was taken from each replication. A rectangle, 1 by 2 inches, was cut from each of 25 leaves. Both sides of the leaves had been sprayed; therefore each sample involved 100 square inches of leaf surface.

In addition analyses were made of spray deposits on the foliage of one-year old apple cutbacks grown in the greenhouse. These trees were grown in 3-gallon earthenware ars. Obviously, it was not possible to make as large a succession of experiments on apple trees because growth of a suitable leaf surface was slower and would have required a much larger amount of greenhouse space than was available. The methods of spraying and analysis were the same as those followed when bean foliage was sprayed.

As a further check on results, analyses were made of deposits on apple foliage sprayed in the orchard. The difficulties in securing uniformity in orchard spraying were much greater than in work in the greenhouse, and all of the earlier work was discarded. In the end the results were found to be much less variable if based on spraying by a single rodman. A single variety was used in each series of experiments, and all trees in each series were sprayed the same day. Each sample taken for analysis of deposits was composed of leaves picked from around the entire circumference of the tree. Usually the fourth leaf from the terminal was selected. All leaves used were in the belt not lower than 3 nor higher than 6 feet from the ground,

the part of the tree most likely to be uniformly sprayed.

PREVIOUS WORK.—Previously, in experiments to measure the effect of spreaders added to lead arsenate on deposits of arsenic, Hamilton (1930) used glass plates as the surface upon which the various spray mixtures were applied. Analyses were made of arsenic deposits on 20 square inches of glass surface, and the averages of five such samples for each material were considered sufficient. Robinson (1925) used 100 square inches of surface of apple leaves. His analyses were based on foliage from sprayed trees, and were undertaken to determine the value of a single spreader, casein-lime, in the spray mixture. More recently in measuring the deposit of arsenic on cabbage foliage, Hervey & Pearce (1942) determined the arsenic on 100 discs varying from 0.67 to 1.0 inch in diameter.

The deposit of arsenic on the surface of apple fruits has been measured by a number of other investigators. The adhesion of a spray material to the surface of a fruit can be expected to be somewhat different from the adhesion to foliage. For this preliminary study, the test of adhesion on a unit area of leaf surface was preferred to a similar area on fruit because of the two, it is easier to measure accurately. Also, it is possible that the adhesion of the insecticide to foliage is in itself as important as adhesion to fruit, since the newly hatched worms may spend considerable time migrating over the leaves before making an entrance into a fruit. It has been shown by Steiner (1939) that larvae may frequently migrate more than 10 feet, and probably a majority of them are destroyed on the foliage.

The arsenical residue was removed by placing the sample first in simmering sodium oleate solution and then in simmering dilute hydrochloric acid in the manner followed in analysis on fruit. A fifth of the sample was treated each time for about 45 seconds in each solution or long enough to wilt the leaves but not long enough to turn them brown. About seven or eight minutes were required to wash the whole sample in the two solutions. The Gutzeit method of analysis, as outlined in official and tentative methods of analysis of the Association of Agricultural Chemists (1930), was used throughout the experiment.

In measuring the effect of the addition of various materials to lead arsenate, only those materials which were used in a single series and applied at one time were directly compared with each other. In each series, one plot was sprayed with the commercial brand of lead arsenate at the rate of one and a half pounds in 50 gallons without the addition of any other material. This was the standard with which all others were compared. The mixtures used on the other plots included the same dosage of lead arsenate and in addition, one of the materials to be tested.

In comparing results, the deposit of arsenic on the standard plot, on which arsenate of lead was used alone, is stated as 100 in the accompanying tables. The statement of deposit of arsenic on other plots shows the percentage deposited in comparison with the standard. The average effect of the addition of a given material is determined by the average percentage of deposit of all plots from all series in which this material is used. These averages from the deposit of arsenic in spraying experiments on lima beans are given in table 1. Departures from 100 indicate the relative reduction or increase of deposit.

RESULTS.—No material added to the spray mixture increased the initial deposit of arsenic. Only one accessory material, bordeaux mixture, 1–1.5–50 formula, appeared not to affect it adversely. Bordeaux mixture, 3–3–50 formula, was among the materials which affected the deposit least.

Of the materials added as a powder, those which were added to increase spreading quality reduced the deposit most. The range in amount of arsenic deposited by such mixtures was from 43.8 per cent of the standard, by one including a proprietary adjuvant, to 79.22 by one including 8 ounces of soyflour. Hydrated lime affected the spray deposit less than any of the powdered adjuvants. Spray mixtures including talc also left a smaller deposit than the standard, but the difference was within the range required for significance. Wettable sulfur is not added to improve the spreading quality of the spray mixture but nevertheless includes a spreader. Mixtures containing this material left an arsenical deposit similar in amount to those containing the common adjuvants. Increased weights, both of

Table 1.—Comparison of proportional amounts of lead arsenate deposited on bean foliage, when used alone, and when in combination with other materials. Dosage of arsenate of lead on all plots at rate of 1.5 pounds to 50 gallons.

Added Material	Dosage in 50 Gallons	Number of Analyses	Percentage of Deposit in Comparison with no Added Material	Least Significant Difference at Odds of 99:1
None	—	180[1]	100	—
Bordeaux	1–1½ lb.	15	98.75	6.95
Bordeaux	3–3 lb.	15	91.94	6.35
Hydrated lime	1½ lb.	15	83.56	4.94
Hydrated lime	4 lb.	9	80.54	4.81
Wettable sulfur	3½ lb.	6	73.16	1.57
Soyflour	8 oz.	15	79.22	4.94
Soyflour	16 oz.	15	75.78	1.85
Milk powder	8 oz.	9	75.46	4.54
Blood albumen	8 oz.	9	61.01	4.70
Proprietary adjuvant #1	4 oz.	9	43.28	4.14
Proprietary adjuvant #2	4 oz.	9	43.28	3.05
Talc	16 oz.	9	95.09	5.04
White summer oil	3 pts.	9	93.49	2.87
Potash fish oil soap	1 lb.	9	54.01	2.87
Proprietary adjuvant #3	.8 oz.	9	42.97	3.37
Proprietary adjuvant #4	2 oz.	9	63.23	4.38
Base of commercial brand used without spreader		9	106.39	4.30

[1] One standard plot with a commercial brand of arsenate of lead without any added material was paired with each test of each combination used.

lime and of soyflour, decreased the arsenical deposits more than smaller dosages, although deposits left by mixtures containing greater and smaller amounts were not significantly less.

Summer oil did not increase the initial deposit of arsenic on an oil free leaf. This might not be true in an orchard where successive applications were made, for it is possible that a spray application with summer oil may also adhere better on a surface that has previously been sprayed with oil, than on one which has not. Furthermore, it does not take into account the fact that lead arsenate applied with summer oil may resist weathering better than when applied alone. The small number of analyses of residue on harvested fruit, which are discussed later, show that the highest accumulated residue was on fruit from commercial orchards which had received a succession of applications including oil.

The commercial brand of lead arsenate, used as the standard, contained a small amount of an added material, presumably to improve its physical properties. A supply of the same brand of arsenate of lead, to which nothing had been added, was secured from the manufacturer for comparison. The deposits of arsenic from the lead arsenate base were 6.4 per cent greater than from the same insecticide sold commercially, to which the manufacturer added an adjuvant.

Increasing the amount of lead arsenate in a spray mixture does not proportionately increase the deposit of arsenic. It does increase the total deposit, but not in proportion to the total amount included in the spray mixture. The reduction in percentage of deposit is similar to that of mixtures in which other powders are added and the percentage of deposit is decreased as the total solids included in the mixture are increased. Lead arsenate was used in experiments at the rate of one, two, and three pounds to 50 gallons of water. If the amount of arsenic deposited on the leaf surface by the mixture including one pound of lead arsenate is rated at 100, the deposits of the total amounts of arsenic from suspensions including two and three pounds, should be rated at 151.14 and 189.45, instead of 200 and 300, respectively.

The analyses of spray deposits shown in table 1 are based on records from spraying bean foliage. The series of experiments from spraying apple foliage are not extensive enough for tabulations. It may be stated that the relative proportion of arsenic deposited by various spray mixtures was similar to that shown by spraying bean foliage. However, the run-off was less and the differences between various mixtures was less. In addition to the accessory materials used with lead arsenate on bean foliage, liquid lime-sulfur at the rate of one and a half gallons in 50 was used on apple foliage. In two replications, the deposit of arsenic applied in this combination averaged 73.65 per cent of that when lead arsenate was applied alone.

In explaining these results, it may be assumed that a finely divided insoluble salt, like lead arsenate, will be deposited on a leaf surface in proportion to the quantity of a spray mixture that will adhere to that surface. Spray mixtures adhere to a wettable surface in greater or lesser quantity according to the nature and amount of materials added to the water, other things being equal. For in-

stance, any material that decreases the angle of contact between a droplet and a wettable leaf surface (below that for water) will hasten coalescence of droplets of spray, and consequently will hasten run-off. The sooner run-off begins, the less lead arsenate will be deposited. Materials like hydrated lime and talc which, when added to the spray mixture, do not noticeably affect the surface tension but increase the solid particles in suspension, will reduce the arsenical deposit. As they settle in hanging drops, or in drops on an inclined leaf, they cause these large drops to coalesce, to break contact with the leaf, and run off. Likewise, any increase in amount of lead arsenate will increase the tendency for hanging and inclined drops to break contact with the leaf surface. As the amount of lead arsenate in the spray mixture is increased, the data show that deposit does not increase in direct proportion.

These experiments show that nearly all of the materials added to a spray mixture which includes lead arsenate decrease the deposit of arsenic on foliage. Thus, they are in agreement with the general results of Hamilton's experiments. Robinson (1925) found in orchard experiments that a single spreader, casein-lime, did not increase the amount of lead deposited.

The results of these experiments raise a question regarding the value of many materials added to the spray mixture to improve it. Spreaders often do increase the evenness of the spray film over the plant surface. The evenness of film may compensate for some part of the resulting decrease in arsenical deposit, but even this may be a doubtful gain. Graham & Richardson (1942) point out that modification of the physical properties of lead arsenate may not result in improved codling moth control. The addition of lime as a corrective for arsenical spray injury may be justified on some plant foliage. As a rule, however, such an addition is unnecessary on apple foliage in Arkansas, since bordeaux mixture, a fungicide included in most spray applications, will serve this purpose and not interfere seriously with the arsenical deposit. Other investigators have shown that an arsenical with an alkaline reaction is not as effective as one with an acid reaction (Swingle 1938). The relative inefficiency of calcium arsenate in comparison with acid lead arsenate has been attributed by Marshall (1937) to this. The addition of lime to lead arsenate has been found to reduce its efficiency in the control of the cabbage worm (Hervey & Pearce 1942).

RESULTS OF MISCELLANEOUS ANALYSES.—During two seasons analyses were made of arsenical deposits on fruit and foliage collected in commercial orchards and in blocks sprayed experimentally. The data which were secured are not sufficient for tabular presentation but are of value in indicating some of the causes of failure in codling moth control. The variability of records from orchard sprayed plots was also a factor in determining the procedure in the preliminary experiments previously referred to.

Analyses of accumulated arsenical deposits on late apples picked just before harvest from orchards, which had been sprayed without oil being included in the mixture, varied from 0.001 to 0.039 grains to a pound of fruit. There was no apparent codling moth control in the orchard from which the samples with the lowest residue were taken. This represents the extremes, for more than 50 per cent of the samples had deposits varying from 0.018 to 0.024 grains to a pound. These samples were taken from orchards, which presumably had been sprayed according to the same schedule and with the same materials. That such a range in arsenical deposits could occur indicates to some extent the very great range in efficiency of spray crews. The statement of Marshall and Groves (1937) directed to fruit growers in Washington that "the majority of growers fail to appreciate either the implication or importance of thoroughness" has a more general application. The highest accumulated arsenical residue of any orchard samples analyzed was .076 grains to a pound and was from an orchard which had been sprayed with mixture including a miscible oil and arsenate of lead in a number of applications.

More extensive and better information was secured on the variations in deposit of arsenic on leaves on different trees in a single block of apples which were sprayed by the same crew and on the same day. These variations were surprisingly great. In an extreme instance from a single spray application, the residue on one tree was nine times that on another nearby tree of the same size and variety. Analyses of

deposit on foliage had been made before and after spraying. This extreme variation was explained by a temporary stalling of the sprayer which undoubtedly allowed the lead arsenate in the spray tank to settle. Since the application of the insecticide was made in combination with a fungicide, there was no indication from the stain on the foliage of any difference in spray deposit. Other causes of failure to secure a satisfactory deposit were charged to failure to replace worn discs in the spray nozzles and a failure to mix the spray materials properly. The first and most obvious conclusion from these analyses is that the variation in personal efficiency of spray crews is much greater than any variation in materials added to arsenate of lead.

In experimental plots the spray crew can be expected to give more than usual attention to even distribution of spray. Even so, in plots where a power sprayer was used, the deposit on foliage from a single application varied from tree to tree as much as 60 per cent. The average was 28 per cent. By the end of the season this difference from tree to tree would be offset in part by the variations in successive applications. Nevertheless, the difference was great enough to obscure the differences in deposit from some of the spray mixtures used. In general, the variations were less as the speed of delivery of the spray by the sprayer decreased. A barrel sprayer had an advantage in this respect over a power sprayer. The most uniform deposits were secured in the greenhouse from spraying apple foliage with an atomizer.

SUMMARY.—In experiments with various accessory materials used in spray mixtures with arsenate of lead, none were found which increased the deposit of arsenic upon foliage. The addition of most of these materials decreased the deposit significantly.

In orchard spraying, the variation in personal efficiency is of such dominating importance that it may completely obscure any differences caused by accessory materials in the spray mixture.—5-12-43.

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GUYTON HEADS BUREAU OF PLANT INDUSTRY IN PENNSYLVANIA

Dr. Thomas L. Guyton has been appointed Chief of the Bureau of Plant Industry of the Pennsylvania Department of Agriculture. Dr. Guyton has been in charge of the Division of Entomology in the same Bureau for some years, his total service with the Department of Agriculture being more than 20 years.

ENTOMOLOGIST NEEDED IN HAWAII

Dr. F. G. Holdaway, head of the Department of Entomology in the University of Hawaii and the Hawaii Agricultural Experiment Station writes that there is an opening for a broadly trained young entomologist at that institution. Preference is indicated for a married man and a Ph.D. is essential. Readers who might be interested should write Dr. Holdaway, preferably by "Clipper" mail, for details.

Early Maturing Varieties in Codling Moth Control[1]

DWIGHT ISELY, *University of Arkansas, Fayetteville*

Early production is frequently used as a means of control of multiple generation insect pests attacking annual crops. It is not usually recommended for the control of such pests on orchard fruits. The relatively long life of the trees does not permit easy change after the time of planting. At that time, consideration is seldom given by the fruit grower to pests which may occur in later years. Nevertheless early production may be a means of evading codling moth injury and should be considered in planting of new orchards, and sometimes shifting the varieties may be useful in reducing damage in established orchards.

Early maturity of apples as a means of control of the codling moth, as of other multiple generation insects, may reduce damage in two ways. It may make possible the harvest of the fruit before maximum numbers of the pest are attained. In addition, the absence of hosts in the latter part of the season may result in starvation of the late generations. To secure the second advantage, it is necessary that plantings of early varieties of apples be separated from those maturing late in the season. If interplanted with late varieties, the infestation is renewed each spring by moths which developed the previous fall as worms in late fruit in the same orchard.

The codling moth has three generations and a part of a fourth in northwestern Arkansas. The third generation is not actually complete since about 15 per cent of the larvae of the second generation, and even a trace of the first generation also, hibernate before pupation. Larvae of the first generation usually begin hatching in early May, the second during the last few days of June, the third during the first week of August, and the fourth about mid-September. The third generation is numerically much the most important, and larvae of this generation do not usually begin to leave the fruit to form their cocoons until after the middle of August, and the majority do not attain their growth until after the middle of September. For this reason, in orchards in which all fruit is harvested before September, the majority of third generation worms are prevented from completing their development, and the number entering hibernation will be greatly reduced. Since, however, about 15 per cent of the larvae of the second generation pass winter before transforming, an infestation can be expected to persist even if harvest is early enough to prevent the development of all third generation larvae. Fruit harvested even as early as the first of July will not eliminate the species entirely for a very few first generation larvae which complete their development in June do not pupate until the next year.

The advantage of early production in isolated blocks of apples in Arkansas has been recognized in a general way for many years, but definite data were lacking (Isely & Ackerman 1923). To secure data regarding the extent of this advantage, in 1941 and 1942 records of worm free fruit were taken in isolated blocks of early summer varieties, in isolated blocks of early fall varieties, in blocks of late fall varieties, and in orchards where the early and late varieties are mixed. The records were made either at harvest or just prior to the time of harvest both of the early summer varieties or of the early fall varieties.

As the summary of seasonal history indicates, the value of early maturity of apples in reducing codling moth abundance is most obvious in isolated blocks of early summer varieties. Orchards which included only the variety Transparent, and which were separated from later varieties by a distance of at least one-fourth mile have been found to be practically worm free at harvest, even though all cover sprays for codling moth control were omitted. (See Table 1, Orchards 1 and 2.) Harvest of this variety in Arkansas sometimes begins a few days before the middle of June which is too early to permit the development of all larvae of the first generation. Harvest is usually completed during the first week of July. The number of worms which pass winter in Transparent orchards is negligible. In Arkansas the variety Dutchess is harvested

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about two weeks later than Transparent. The only isolated block of Dutchess in which records of infestation were made (Table 1, Orchard 3) was also relatively free from infestation, although the infestation was potentially heavier than in the isolated Transparent orchards. Probably this was because its harvest was a little later, and because this orchard was only 300 yards from a block of late apples. This orchard received two cover sprays.

Unfortunately, from the viewpoint of worm control, early summer varieties are not usually planted in separate blocks, but are mixed with or planted adjacent to late varieties. Thus the advantage of isolation is lost, for worms which developed on late varieties the preceding season have passed winter in the orchard. The early apples interplanted with late varieties are frequently very heavily infested, and at the time of early apple harvest are invariably more heavily infested than the adjacent late varieties. (See Table 1, Orchards 4, 5, and 6.) In part, this is because ripening fruit is more susceptible to worm injury than late fruit, in that it is more attractive to ovipositing moths or the surface is easier for newly hatched larvae to penetrate. Also, to reduce spray residue, the early maturing fruit usually received less than the full number of spray applications, and as a result, serves as a source of infestation for later varieties.

The isolation of varieties which are harvested in early fall before a majority of the third generation worms have developed reduces the severity of the codling moth problem. The Jonathan variety is an example of one which ripens at such a time. During an average season, harvest begins the third week in August and is practically completed by the end of the first week of September. Although it is one of the most important varieties grown in northwestern Arkansas, there are relatively few blocks which do not also include other varieties which are harvested in October. In all of the orchards where records were made, both early fall and late fall varieties occurred. In some of these orchards, however, the early fall apples were in separate blocks so that a part of the advantage of earliness was secured. In some orchards it was possible to secure records of the percentage of worm free fruit in blocks containing only early fall apples and also in blocks containing both Jonathan and later varieties (Table 2, Orchards 7 and 8). Such records have an advantage in that both blocks were under the same management and sprayed by the same crews. In both of these orchards the separate blocks of Jonathan had much lower infestations than the mixed blocks, although a smaller number of spray applications were made in the isolated blocks. In two other orchards records were taken of infestations of Jonathan and also of late fall varieties in separate blocks and under the same management. (Table 2, Orchards 9 and 10). In a single orchard records were made of infestations of Jonathan and later varieties interplanted in the same orchard (Table 2, Orchard 11). While these records show that the problem of control of the codling moth is lighter in blocks of early fall apples if they are separated from later varieties, heavy loss may nevertheless occur. Records not included in these tables were taken in a few isolated blocks of early fall apples which received inadequate protection by spraying, and in these orchards the loss was nearly total.

Table 1.—Worm free fruit at time of early summer apple harvest in orchards of early summer varieties isolated from late varieties, and in mixed blocks of early summer and late varieties.

Character of Planting	Orchard No. Variety	Percentage Worm Free Fruit	Spray Applications Prior to Early Apple Harvest
Isolated early varieties	Orchard 1 Transparent	95.25	Calyx spray
	Orchard 2 Transparent	99.25	Calyx spray
	Orchard 3 Dutchess	94.50	Calyx and 2 cover sprays
Mixed early and late varieties	Orchard 4 Transparent	52.00	Calyx and 3
	Late fall	94.50	cover sprays
	Orchard 5 Transparent	48.35	Calyx and 3
	Early fall	88.00	cover sprays
	Orchard 6 Dutchess	77.50	Calyx and 3
	Early fall	97.50	cover sprays

The records taken in northwestern Arkansas are supported by observations on Crowley's Ridge in the northeastern part of the state, where there are a few large isolated plantings of the variety Delicious which is handled there as a

late summer variety. In such orchards, where this variety is harvested in August, codling moth control has never presented a serious problem. In other orchards in the same general region, where Delicious and varieties harvested in October are grown together, the problem of codling moth control appears to be very difficult.

Table 2.—Worm free fruit in orchards of an early fall variety isolated from late fall varieties and in mixed orchards of early fall and late fall varieties, at time of early fall apple harvest.

ORCHARD NO. VARIETY	PERCENTAGE WORM-FREE FRUIT	SPRAY APPLICATION
Orchard 7		
Jonathan block isolated	83.50	Calyx and 6 cover sprays
Jonathan mixed with late fall varieties	30.00	Calyx and 6 cover sprays
Orchard 8		
Jonathan block isolated	82.67	Calyx and 4 cover sprays
Jonathan mixed with late fall varieties	37.00	Calyx and 4 cover sprays
Orchard 9		
Jonathan isolated	95.00	Calyx and 4 cover sprays
Late fall variety Separate block	61.50	Calyx and 6 cover sprays
Orchard 10		
Jonathan isolated	96.48	Calyx and 4 cover sprays
Late fall varieties Separate blocks	91.25	Calyx and 6 cover sprays
Orchard 11		
Jonathan mixed	33.00	Calyx and 6 cover sprays
Late fall variety mixed	37.50	Calyx and 6 cover sprays

SUMMARY.—The codling moth in northwestern Arkansas is dominantly a 3-generation species, although a very few larvae of the first generation and about 15 per cent of the second generation pass winter before transforming to pupal stage. There is also a partial fourth generation. For this reason, there is little worm injury in orchards of varieties which are harvested by the time worms of the second generation are beginning to hatch (which is about July 1), provided those orchards are isolated from later varieties. Under such conditions the late generations, upon which the succeeding season's infestation depends, cannot develop. In orchards where early summer apples have been isolated from late apples, there has been no problem of codling moth control.

In orchards where early varieties of apples are interplanted with early fall or late fall varieties, the problem of control may be difficult since the late generations of the codling moth can survive the latter part of the season in late varieties of apples and enter hibernation in the orchard. Early as well as late varieties are exposed to infestation by the overwintered generation. Furthermore, early ripening fruit in infested orchards is particularly susceptible to injury.

Early fall varieties which ripen before a majority of worms of the third generation have left the fruit, if grown in blocks separate from later varieties, do not present as difficult a problem of control as late fall varieties, but nevertheless require adequate protection by spraying. Mixing blocks of early fall and late fall varieties makes the problem of control more difficult.

In view of the dominating importance of the codling moth problem in apple production in the southern apple regions, one should consider when planting commercial orchards, the grouping together in blocks of apple varieties which are harvested at the same time. Such grouping of varieties can make the problem less difficult, and reduce spray costs. Early production as a means of codling moth control may be even more useful when planting home orchards, which are generally inadequately sprayed, and when composed of mixed plantings, tend to produce no good fruit.—5-12-42.

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DR. F. L. CAMPBELL IN WASHINGTON

Dr. Frank L. Campbell, formerly of Ohio State University, has accepted the position of Director of Publications of the American Association for the Advancement of Science and may be found in the Smithsonian Institution Building in Washington.

Dr. Campbell has established his residence in Rockville, Maryland, at 18 Forest Avenue.

Orchard Tests of Chemically Treated Bands for Codling Moth Control in the Missouri River Valley

HOWARD BAKER,[1] *U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine*

Experiments were conducted in the Missouri River Valley, near Saint Joseph, Mo., during the period 1935 to 1938, inclusive, to determine what amount of chemical coating is necessary to insure the efficiency of treated bands for use in this area against the larvae of the codling moth. The experiences of Filinger (1936) and Patton (1936) in Kansas, together with the failure of treated bands to perform as expected when used by local growers in 1934, indicated the need for such an investigation. Treated bands in use at that time were prepared according to any one of several definite, recommended procedures, but few of the recommendations included any mention as to what amount of chemical would or should be deposited on the bands. Subsequent investigations have shown that the amount of chemical coating deposited on bands may be greatly modified by slight variations in the method or manner of treatment (Filinger 1936, Worthley & Marston 1936, and Woodside 1938). In an earlier publication Siegler & Munger (1932) recommended that bands be given a chemical coating of at least 1 ounce per linear foot of 2-inch band until such time as additional tests indicated the efficiency of lighter coatings. In later published papers (Wakeland & Haegele 1934, Worthley & Marston 1936, Washington State College 1936, and Woodside 1938) lighter coatings, which ranged from approximately one-third to four-tenths of an ounce per linear foot of 2-inch band, have been recommended. These recommendations indicate that the quantity of chemical coating necessary for satisfactory performance may vary from one section to another, and that slightly heavier coatings of the material are needed in regions of high rainfall than in arid regions.

MATERIALS AND METHODS.—All bands used in the experiments reported herein were prepared by E. H. Siegler of the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture. Methods of preparing chemically treated bands have been described adequately by Siegler & Munger (1932), Worthley & Marston (1936), and Woodside (1938) and need not be repeated here. Suffice it to say that the chemical treatments for these experiments were based on the use of 1 pound of beta naphthol to 1.5 pints of mineral oil, plus, when used, 0.5 ounce of aluminum stearate, and were applied to single-face corrugated paper which was 2 inches wide and had 36 to 40 corrugations per foot. Cold-dipped bands were prepared by dissolving the aforementioned materials in gasoline, the quantity of gasoline used being varied according to the amount of chemical coating desired.

The bands were applied to the trees each season in time to capture first-brood worms, and 20 trees, arranged in 5 replications of 4 trees each, were used for each treatment. Twice each week, while they were in operation, the bands were examined for protruding dead larvae and cast pupal skins, except in 1935, when they were examined three times each week. The bands were removed and final examination made each fall, but not until at least 2 weeks after completion of harvest, except in 1935, when they were left in place until the following spring.

CONDITIONS AFFECTING RESULTS.—Rain and high temperatures are generally considered to be the most important factors causing loss of the chemical coating from treated bands. During the period 1935 to 1938, inclusive, rainfall ranged from near to much below normal, and temperatures usually from near to much above normal. In 1935 temperatures were much below normal in June, much above normal in July, and near normal the remainder of the season, while rainfall was moderately below normal throughout the season. In 1936 temperatures were much above and rainfall moderately below normal throughout the season. In 1937 temperatures were much above normal in July and August and near normal the remainder of the season, while rainfall was

[1] H. G. Butler, E. W. Cook and Kenneth Lamansky assisted in the application, periodical examination, and removal of bands, and F. M. Wadley furnished advice and assistance in connection with the statistical analysis of the data.

generally below normal except in July, when it was much above normal. In 1938 temperatures were much above normal throughout the season, and rainfall was considerably below normal except in August, when it was considerably above normal.

Since codling moth larvae cease to transform at about the same time each season, the length of time that bands must remain in operation and retain their effectiveness is governed by the time when codling moth larval activity begins in the spring. This activity began 2 weeks late in 1935, at about the normal time in 1936 and 1937, and 10 days early in 1938.

RESULTS.—The treatments tested and the results effected by them are given in table 1, together with the differences between treatments, calculated by analysis of variance, necessary for significance. Since a large portion of the hibernating larvae in the bands of 1935 were killed by low winter temperatures and not by the band treatments, the least significant difference between the treatments in terms of normal, live larvae present at the time of the final examination of the bands of that season was not calculated. For this reason, also, bands were removed in the fall in subsequent seasons.

A simple comparison of treatments based on moth emergence is all that is necessary from a practical standpoint, but a more critical comparison based on the normal, live larvae in the bands at the end of the season is believed of value also, as indicating what treatments retain a high degree of toxicity to or near to the end of the season and what ones do not. As between two treatments of equal efficiency from the standpoint of moth emergence, one would expect the one resulting in the fewer normal, live larvae to be the more effective year after year under all conditions.

From the standpoint of moth emergence, all treatments tested were highly efficient with few exceptions. Few of the differences in moth emergence between treatments were consistently significant. However, there was a tendency for the lower dosages, or loads of chemical coating, to permit more moths to emerge than the higher ones.

From the standpoint of normal, live larvae in the bands at the end of the season, differences between treatments were greater and more consistent than when based on moth emergence. There was a decided tendency for the bands with the lighter chemical coatings to contain more living, healthy larvae than those with the heavier ones. Bands with an initial chemical coating of approximately 0.40 ounce per linear foot generally contained a smaller percentage of normal, live larvae at the end of the season than those with lighter coatings.

Comparison of treatments 1 and 5 with treatments 2, 3, and 4 indicates that properly prepared hot-dipped and cold-dipped bands are equally effective and satisfactory.

Comparison of treatment 2 with treatments 1, 3, 4, and 5 indicates that crude and technical beta naphthol are equally satisfactory for use in the preparation of chemically treated bands.

Comparison of treatment 4, tested only in 1935, with treatments 1, 2, 3, and 5 indicates that the viscosity of oil used in the preparation of chemically treated bands is not important within the range of oils tested.

Comparison of treatment 1 with treatment 5 indicates that aluminum stearate improves the efficiency of hot-dipped bands somewhat under some conditions. The differences appeared to be the widest in 1937 and 1938, especially as indicated by the percentage of larvae found alive and normal when the bands were examined at the close of the season. Excessive rainfall occurred during July 1937 and August 1938, and it seems likely that the aluminum stearate in the bands prepared by formula 1 aided in the retention of the chemical coating.

WEATHERING OF BANDS.—The rate and degree of weathering of the chemical coating on treated bands were studied during 1936 and 1937. Three bands applied to orchard trees as in ordinary practice were used for each test of each treatment and left exposed to natural weathering conditions for periods of from 1 to 4 months.

The results of chemical analysis of the residues on a set of bands that weathered for 3 months in 1936 are given in table 2. Temperatures were very high and rainfall was low during the time that this set of bands was exposed in the orchard. The results indicate that the loss of chemical coating from bands during a period of 3 months is very heavy regardless of the method of, or the materials used in, their

Table 1.—Results of orchard tests of chemically treated bands, St. Joseph, Mo., 1935 to 1938, inclusive.

Formula	Dosage in Ounces[1]	1935 Total Number of Larvae Caught	1935 Per Cent Developed into Moths	1935 Per Cent Remained Alive and Normal	1936 Total Number of Larvae Caught	1936 Per Cent Developed into Moths	1936 Per Cent Remained Alive and Normal
1. Hot dipped, using tech. beta naphthol, 100-vis. oil, and aluminum stearate	.51	445	.7	1.3	761	1.0	1.0
	.42	—	—	—	1070	2.5	1.9
	.32	553	.4	2.0	1357	1.9	5.4
	.20	651	2.2	10.1	1453	3.6	11.0
2. Cold dipped, using crude beta naphthol and 100-vis. oil.	.73	742	.3	1.5	1209	.5	.9
	.51	675	.4	1.8	1469	.9	2.4
	.41	—	—	—	1636	2.4	14.7
	.32	570	.2	3.5	1125	1.2	16.7
3. Cold dipped, using tech. beta naphthol and 100-vis. oil.	.76	636	.5	1.9	1125	1.3	2.1
	.51	438	.2	4.1	1043	1.2	6.8
	.41	—	—	—	1340	4.0	10.5
	.33	662	.3	7.8	948	9.2	16.8
4. Cold dipped, using tech. beta naphthol and 300-vis. oil	.77	508	1.2	.6	—	—	—
	.46	534	.2	1.7	—	—	—
	.35	522	.4	4.8	—	—	—
5. Hot dipped, using tech. beta naphthol and 100-vis. oil.	.73	872	.3	.9	859	1.6	1.2
	.50	832	2.4	7.8	1126	1.7	5.2
	.43	—	—	—	1146	2.0	6.5
	.33	736	2.0	7.2	977	2.5	13.9
Untreated check	.00	397	15.6	35.8	912	41.2	51.2
Least significant difference (check omitted)		P=.01	1.6	—		3.5	8.2
		P=.05	1.2	—		2.6	6.2

[1] Refers to amount of chemical coating per linear foot of 2-inch-width band.

Formula	Dosage in Ounces	1937 Total Number of Larvae Caught	1937 Per Cent Developed into Moths	1937 Per Cent Remained Alive and Normal	1938 Total Number of Larvae Caught	1938 Per Cent Developed into Moths	1938 Per Cent Remained Alive and Normal
1. Hot dipped, using tech. beta naphthol, 100-vis. oil, and aluminum stearate.	.52	3624	1.4	3.0	4760	1.1	4.2
	.40	3340	1.0	4.0	4763	1.2	5.4
	.31	2301	1.0	10.3	—	—	—
5. Hot dipped, using tech. beta naphthol and 100-vis. oil.	.75	2182	0.6	3.4	—	—	—
	.50	2770	1.7	13.2	4662	3.2	16.4
	.40	1641	2.2	18.4	4192	2.4	13.5
Untreated check	.00	1275	20.4	75.1	5215	19.9	74.6
Least significant difference (check omitted)		P=.01	1.0	7.0		1.6	4.6
		P=.05	0.7	5.2		1.2	3.3

preparation, that the percentage loss of beta naphthol is also heavy and not in proportion to loss of total coating, that the percentage loss of beta naphthol may be either greater or less than the percentage loss of total coating, and that the percentage loss of beta naphthol is greater from the lighter than from the heavier chemical coatings. Loss of beta naphthol was almost complete from all bands pro-

Table 2.—Loss of chemical from the coating of treated bands exposed to weathering for a period of 3 months, Saint Joseph, Mo., 1936.[1]

Formula	Ounces of Chemical Coating per Foot of Band June 30	Ounces of Chemical Coating per Foot of Band Sept. 30	Per Cent of Chemical Coating Lost	Ounces of Beta Naphthol per Foot of Band Sept. 30	Per Cent of Beta Naphthol in Chemical Coating Sept. 30
1. Hot dipped, using tech. beta naphthol, 100-vis. oil, and aluminum stearate.	.52 .30	.18 .15	65 50	.019 .003	10.6 2.0
3. Cold dipped, using tech. beta naphthol and 100-vis. oil.	.55 .31	.25 .11	55 65	.060 .002	24.0 1.8
5. Hot dipped, using tech. beta naphthol and 100-vis. oil.	.52 .30	.17 .12	67 60	.014 .0014	8.2 1.2

[1] Analyses made by Division of Insecticide Investigations, Bureau of Entomology and Plant Quarantine, Washington, D. C.

vided with a coating of 0.30 ounce of chemical per foot of band, a strong indication of the inadequacy of this or lighter coatings for use in the Missouri River Valley.

Chemical analyses of weathered bands were not obtained in 1937, but, since all bands used were of equal size and were weighed both before and after weathering, records of the rate and degree of loss of their total coating are available. These are given in table 3, together with the difference between variables, calculated by an analysis of variance, necessary to indicate significance. In the analysis of variance it was not possible to separate a clear-cut error term because of the fact that differences between periods may be viewed as partly controlled and partly uncontrolled variation. However, the pooled variance of interactions with period was found to be a highly conservative estimate of random variation affecting treatment comparisons and was used as error.

The data indicate that loss of chemical coating was heaviest the first month that the bands were exposed to weathering,

Table 3.—Percentage loss of chemical coating from treated bands exposed to weathering for periods of 1 to 4 months, Saint Joseph, Mo., 1937.

Period of Exposure	Mean Temperature in Degrees F.	Average Inches of Rain per Month	Formula 1. Hot Dipped, Using Tech. Beta Naphthol, 100-vis. Oil, and Aluminum Stearate		Formula 3. Cold Dipped, Using Tech. Beta Naphthol and 100-vis. Oil		Formula 5. Hot Dipped, Using Tech. Beta Naphthol and 100-vis. Oil		Formula 6. Hot Dipped, Using Tech. Beta Naphthol and 300-vis. Oil.		Mean Percentage Loss During Period (All Formulas and Dosages)
			Ounces of Chemical Coating per Linear ft. of 2-in. width band								
			0.50	0.30	0.30	0.30	0.50	0.30	0.50	0.30	
1 month—											
June 26–July 26	80.4	5.97	17.4	17.5	21.4	19.8	28.8	22.5	27.8	14.9	21.3
Sept. 29–Oct. 26	56.0	1.26	18.9	12.3	15.3	14.9	21.4	23.9	15.2	9.0	16.4
2 months—											
June 26–Aug. 26	80.7	5.57	31.5	25.2	34.5	27.5	40.7	36.4	38.5	28.5	32.8
Aug. 26–Oct. 26	65.2	1.04	27.4	21.8	19.4	23.7	31.7	33.2	29.8	13.9	25.1
3 months—											
June 26–Sept. 29	77.8	3.98	36.1	37.9	43.4	46.3	44.2	44.1	42.4	32.7	40.9
July 26–Oct. 26	70.9	2.41	34.4	30.4	28.4	34.5	42.3	34.2	39.8	27.6	34.0
4 months—											
June 26–Oct. 26	73.0	3.30	41.2	42.9	49.1	48.9	51.2	42.8	50.0	40.7	45.8
Mean percentage loss (formulas)			28.2		30.5		35.3		29.3		
Mean percentage loss (dosage, all formulas and periods)									32.9	28.9	

Difference required between any two mean percentages for:

	Formulas	Dosages	Periods
5% level of significance	2.42	1.71	3.20
1% level of significance	3.24	2.29	4.28

that significant further losses occurred as the period of exposure increased, and that losses were as a rule significantly greater from bands having the heavier than from those having the lighter initial coating. The data indicate, also, that differences in loss of chemical coating between bands prepared according to formulas 1, 3, and 6 were small and not significant, while the loss of chemical coating from bands prepared according to formula 5 was significantly greater than that from those prepared according to the other formulas. It would appear, therefore, that aluminum stearate is a worth-while ingredient of the formula by which hot-dipped bands are prepared when 100-viscosity oil is used. Higher temperatures and greater rainfall happened to be associated in this particular series of experiments, and one or both of these factors caused a significantly greater loss of the chemical coating.

SUMMARY AND CONCLUSIONS.—The data indicate that chemically treated bands with a uniform coating were highly efficient when used in the Missouri River Valley during the years 1935 to 1938, inclusive, in preventing the development of the codling moth larvae that cocooned in them, whether they were hot or cold dipped, regardless of the grade of beta naphthol or the viscosity of oil used in their preparation, and at all dosages, with few exceptions, within the range of those tested. The data indicate, also, that the inclusion of aluminum stearate in the formula used for the preparation of hot-dipped bands made with technical beta naphthol and 100-viscosity oil not only increased the resistance of their coating to weathering but also appeared to increase their efficiency in wet seasons. Bands provided with a chemical coating of 0.40 ounce or more per linear foot of 2-inch-width band held the percentage of normal, live larvae in them at the end of the season to a low level more consistently than those with lighter coatings. This is believed to indicate strongly that 0.4 ounce is the minimum chemical coating that will insure that bands used in the Missouri River Valley will maintain a high degree of efficiency in preventing the development of captured larvae into moths in all seasons, regardless of whether conditions are normal or extremely abnormal.

It is believed that chemically treated bands prepared for use in the Missouri River Valley will be highly efficient if they are properly prepared with a uniform chemical coating, whether they are hot or cold dipped or whether the grade of beta naphthol is crude or technical, and if the viscosity of the mineral oil is within the range of from 100 to 300 seconds Saybolt at 100° F. In order to provide a reasonable margin above the minimum chemical coating indicated as necessary to prevent the emergence of more than a minimum number of moths, the bands should have a uniformly distributed coating of at least 0.40 ounce of chemical per linear foot of 2-inch band, and, if the bands are prepared by the hot-dip method, the inclusion of aluminum stearate in the formula should add somewhat to their effectiveness.—5-26-43.

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Propylene Dichloride for Peachtree Borer Control

OLIVER I. SNAPP, *U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine*[1]

Experiments with propylene dichloride for control of the peachtree borer, *Sanninoidea exitiosa* (Say), were started in the spring of 1941 to determine whether that material would provide a greater margin of safety than ethylene dichloride at strengths sufficient to control the borer.

Propylene dichloride ($CH_3CHClCH_2Cl$) is a clear, colorless liquid with an odor somewhat similar to that of ethylene dichloride. According to information furnished by the manufacturer, it boils at 95.4° C. (203.7° F.), freezes at −70° C. (−94° F.), has a specific gravity at 25/25° C. of 1.159, and, like ethylene dichloride, is inflammable. It is very soluble in alcohol or ether at 25° C., but its solubility in water is only 0.27 gm. per 100 gm. of water at 20° C.; however, it is fairly stable in the presence of water. A gallon of the compound at 25° C. weighs 9.64 pounds. No harmful results should be feared in working with propylene dichloride unless it is breathed at high concentrations over a protracted period.

PRELIMINARY EXPERIMENTS.—The first experiments with propylene dichloride were started on April 10, 1941, at Fort Valley, Ga., to determine its effect on peach trees. As no tree injury resulted from the same dosages and strengths recommended for ethylene dichloride, a series of experiments was started on May 10, 1941, to determine the comparative effectiveness of propylene dichloride and ethylene dichloride for control of the peachtree borer. These experiments indicated that propylene dichloride is very effective against the peachtree borer at a strength lower than that required for good borer control with ethylene dichloride. In the fall of 1941 an opportunity was presented to test the comparative effectiveness of propylene dichloride and ethylene dichloride against the peachtree borer in a very heavily infested 10-year-old peach orchard at the United States Horticultural Station at Beltsville, Md. Emulsions of these materials made by the cold-stirred method, using 1 part by volume of a 30 per cent solution of potash-fish-oil soap of good grade and 9 parts by volume of the chemical, were applied on October 4. The results taken 3 days later confirmed those of previous experiments in that the propylene dichloride emulsion gave equal borer control when applied at a strength one-fourth less than that required of ethylene dichloride emulsion.

EXPERIMENTS WITH THE EFFECT OF PROPYLENE DICHLORIDE ON PEACH TREES AT BELTSVILLE, MD., 1941–42.—Experiments were started during the fall of 1941 at Beltsville, Md., on 3-year-old seedling peach trees in Beltsville silt loam and Hyattsville silt loam, the type of soil found to be most conducive to injury to peach trees from the use of ethylene dichloride, as revealed by experiments conducted at Beltsville in 1940. When ethylene dichloride is used for control of the peachtree borer, ½ pint of 15 per cent emulsion[2] is recommended for 3-year-old trees. It was decided to test propylene dichloride emulsion at that quantity and strength, applying it on the soil around the base of the tree in such a way that none of the material would touch the trunk directly, in 4 different treatments, as follows: (1) On dry soil at the regular time in October for applying ethylene dichloride emulsion for peachtree borer control, (2) on very wet soil at the regular time in October for applying ethylene dichloride emulsion for peachtree borer control, (3) on dry soil about the middle of November, and (4) on very wet soil about the middle of November. Since there was very little rainfall during October and November 1941, water was applied with a sprayer to the ground around the base of certain of the trees the day before they were treated. Trees treated on October 9 received 15½ gallons of water each on October 8; those treated on November 18 received 16¾ gallons of water each on the preceding day. The water-holding capacity of the soil types to which these treatments were applied

[1] The writer gratefully acknowledges the cooperation of the Bureau of Plant Industry, which furnished the trees for the experiments at Beltsville, Md., and equipment and help for pulling some of the trees and applying water in certain of these experiments. Special thanks are extended to F. P. Cullinan, assistant chief, and Donald H. Scott for participating in the examination of the experiment trees.

[2] All strengths of diluted emulsions are expressed in terms of percentages by volume.

was 20 per cent, and the wilting coefficient 8 per cent of moisture. Each experiment was replicated 3 times and each replicate consisted of 3 trees. A replicate of 3 check or untreated trees was maintained for each replicate of treated trees. A total of 72 3-year-old peach trees was used for these experiments. The emulsion was prepared by the method previously described.

The final results were taken on April 22, 23, and 24, 1942. This was done by removing the bark and cambium layers all around each tree from the roots up the trunk with a sharp hatchet, and two-thirds of the trees were pulled out of the ground with a tractor so that the root system could be carefully examined for injury. The results of these experiments are given in table 1. Three tree plats were replicated three times.

Table 1.—Experiments to determine the effect on the trees of a half pint of 15 per cent propylene dichloride emulsion applied to Beltsville or Hyattsville silt-loam soil around 3-year-old peach trees under orchard conditions at Beltsville, Md., 1941–42.

Date of Application	Average Water in Soil		Results of Examination for Tree Injury, April 22, 23, and 24, 1942
	First 4 Inches	First 12 Inches	
1941	*Per Cent*	*Per Cent*	
Oct. 3 and 4	3.94	5.00	No injury (9 trees)
Oct. 9	17.00	14.00	No injury (9 trees)
Nov. 12	10.30	8.10	No injury to 8 trees; one small spot of injury in cambium of 1 tree, but not serious.
Nov. 18	17.00	18.00	No injury to 4 trees; small bark area injured on 1 tree; small spot of injury in wood at root of 1 tree; 3- by 1-inch spot of injury in wood of 1 tree; 2- by 2-inch spot of injury in wood of 1 tree; injury in wood on one side of 1 tree. None serious and all would recover.

In the preliminary experiments a half pint of 10 per cent propylene dichloride emulsion gave complete control of the peachtree borer in 3-year-old trees; thus in the present experiments the material was used at a strength at least one-third greater than that required for peachtree borer control. It is therefore apparent from table 1 that propylene dichloride emulsion applied at this excess strength on heavy soil in the manner previously described caused no injury to 3-year-old peach trees when used at the usual time in the fall, irrespective of whether the soil was very dry or very wet, and when used late in the fall it caused practically no injury to 3-year-old trees in dry soil and only minor injury to similar trees in very wet soil. The comparable check trees that were left untreated in each instance showed no injury.

When applied on heavy soil in a similar manner and at the same strength and quantity, ethylene dichloride emulsion caused no injury to 3-year-old peach trees whether applied at the usual time or late in the fall, irrespective of whether the soil was dry or wet.

EXPERIMENTS IN GEORGIA.—Experiments conducted at Fort Valley, Ga., during the early months of 1942 showed that, even when applied in cold wet soil, propylene dichloride emulsion could be used effectively against the peachtree borer in midwinter in the South at a strength lower than that required of ethylene dichloride. They showed also that this material at a strength one-fourth lower than required of ethylene dichloride was more effective than the latter in very wet soil in the spring, and that at this same strength in the late spring it killed all the 28 borers present in 20 trees 4 years of age or older. Complete control of the borer in 4-year-old trees was also obtained from propylene dichloride emulsion applied at a strength just half that recommended for ethylene dichloride, but this was not quite strong enough when used on older trees.

More extensive tests of propylene dichloride at various strengths, in comparison with ethylene dichloride and paradichlorobenzene for peachtree borer control, were conducted on 1-, 2-, 3-, 4-, and 6-year-old peach trees in commercial orchards at Fort Valley, Ga., during the fall of 1942. These orchards were on Greenville silt loam and Greenville sandy loam, the former type being most conducive to injury to peach trees from ethylene dichloride. Each treatment was replicated 5 times on randomized plats of 3 trees each with 5 randomized replicates of 3 untreated or check trees for each age group. A total of 390 trees were used for

the experiments. The emulsions were prepared and applied according to the method previously described, and the paradichlorobenzene crystals were applied in the usual manner. The applications were made on October 20, 21, and 22. Before treatment the soil level was raised above the topmost borer gallery in cases where there were signs of borers in the tree above the normal soil level. The trees were mounded with soil following the paradichlorobenzene treatments, and several shovelfuls of soil were placed on the treated surface after the emulsions were applied. The soil was dry when the materials were applied and remained so until November 23. The soil was very warm during the first week following the applications, favoring rapid action from the chemicals used in these experiments.

Table 2.—Experiments with propylene dichloride, ethylene dichloride, and paradichlorobenzene applied on October 20–22, 1942, for control of the peachtree borer at Fort Valley, Ga.

Material Applied per Tree	Results (Nov. 3–Dec. 1, 1942) Total Borers	Borers Dead	Tree Injury
	Number	*Per Cent*	
Six-year-old Trees			
Ethylene dichloride emulsion, 8 oz. of 20 per cent	33	91	None
Propylene dichloride emulsion, 8 oz. of 20 per cent	23	96	None
Propylene dichloride emulsion, 8 oz. of 15 per cent	18	100	None
Propylene dichloride emulsion, 8 oz. of 13½ per cent	13	100	None
Paradichlorobenzene crystals, 1 ounce	25	84	None
Check, untreated	116	0	None
Four-year-old Trees			
Ethylene dichloride emulsion, 8 oz. of 20 per cent	23	91	None
Propylene dichloride emulsion, 8 oz. of 20 per cent	34	100	None
Propylene dichloride emulsion, 8 oz. of 13½ per cent	41	100	No injury to 14 trees; spot size of a half dollar injured through cambium just below borer wound on 1 tree.
Paradichlorobenzene crystals, 0.75 ounce	51	88	Some bark injury to 6 trees; no injury to 9 trees.
Check, untreated	102	1	None
Three-year-old Trees			
Ethylene dichloride emulsion, 8 oz. of 13½ per cent	6	83	None
Propylene dichloride emulsion, 8 oz. of 13½ per cent	7	100	None
Propylene dichloride emulsion, 8 oz. of 10 per cent	6	100	No injury to 14 trees one small injured spot in bark layers only of 1 tree.
Paradichlorobenzene crystals, 0.5 ounce	15	53	2- by 2-inch area injured through cambium into wood of 1 tree; bark injury to 6 trees; no injury to 8 trees.
Check, untreated	85	0	None
Two-year-old Trees			
Ethylene dichloride emulsion, 4 oz. of 15 per cent	4	100	None
Propylene dichloride emulsion, 4 oz. of 15 per cent	9	100	Serious injury to 2 small trees; one side of 3 trees injured; slight injury to 6 trees; no injury to 4 trees.
Propylene dichloride emulsion, 4 oz. of 10 per cent	3	100	Spot size of a quarter injured in bark only of 1 tree; small area of 1 tree slightly injured in first bark layer only; no injury to 13 trees.
Paradichlorobenzene crystals, 0.5 ounce	2	100	Serious injury through cambium and into wood of 3 trees, 2 of which are completely girdled; 1 tree injured into wood at one place; 1 tree moderately injured; bark injury to 2 trees; no injury to 8 trees.
Check, untreated	22	0	None
One-year-old Trees			
Ethylene dichloride emulsion, 2 oz. of 7.5 per cent	1	100	None
Propylene dichloride emulsion, 2 oz. of 7.5 per cent	4	100	None
Propylene dichloride emulsion, 2 oz. of 3 per cent	4	50	None
Paradichlorobenzene crystals, 0.75 ounce	1	100	Serious injury through cambium and into wood of 6 trees, 5 of which are completely girdled; moderate injury to 5 trees; no injury to 4 trees.
Check, untreated	6	0	None

Examinations for borer mortality and tree injury were made during the period November 3–6, 2 weeks after the treatments with ethylene dichloride and propylene dichloride emulsions; on November 17 and 18, 4 weeks after the treatment of 1-, 2-, 3-, and 4-year-old trees with paradichlorobenzene; and on December 1, 6 weeks after the treatment of 6-year-old trees with paradichlorobenzene. The check or untreated trees were examined at the time the examinations were made for results from the paradichlorobenzene treatments. The results of these experiments are given in table 2.

In each age group considerably more borers were found in the check or un-

treated trees than in the treated trees because many dead borers, especially those less than one-eighth grown, had so decomposed and disintegrated that they could not be found when the treated trees were examined 2 to 6 weeks after treatment. Therefore the percentage of dead borers recorded for the several treatments is undoubtedly lower than of those which actually died, but is adequate for comparing the borer mortalities caused by the materials used in these experiments.

The results of these experiments show that propylene dichloride is more effective than ethylene dichloride against the peachtree borer, even when used from one-fourth to one-third weaker than recommended for ethylene dichloride. Propylene dichloride proved to be more toxic to peach trees 4 years of age and under than ethylene dichloride, but in only two cases was serious tree injury from propylene dichloride recorded. Both of these were small 2-year-old trees, each of which had received 4 ounces of 15 per cent propylene dichloride emulsion, which is the quantity and strength of ethylene dichloride recommended for use on trees of that age. No injury was recorded from ethylene dichloride in the strength and quantity recommended for use around the trees of the several ages in these experiments. When used from a fourth to a third weaker than recommended for ethylene dichloride, propylene dichloride caused practically no tree injury and gave excellent control of the peachtree borer. Used at the reduced strengths it was the cheaper treatment, since both materials cost approximately the same per pound. The indications are that good borer control without tree injury can be expected from propylene dichloride emulsion when used at considerably less strength than required for good borer control from ethylene dichloride, but further experimentation appears desirable.

These results confirm previous experiments conducted by the writer, which showed that paradichlorobenzene crystals may cause serious tree injury in the Fort Valley, Ga., area when used around young peach trees for the control of the peachtree borer. In these tests both propylene dichloride and ethylene dichloride were more effective than paradichlorobenzene crystals against the insect on trees 3 years of age and older.

SUMMARY.—Experiments with propylene dichloride emulsion for control of the peachtree borer have been conducted at Fort Valley, Ga., since April 1941, and other experiments with that material have been carried on at Beltsville, Md. Propylene dichloride emulsion applied at the same strength and quantity as recommended for ethylene dichloride emulsion caused no injury to 3-year-old seedling peach trees in Beltsville or Hyattsville silt-loam soil when used at the usual time in the fall in either very dry or very wet soil and only minor injury when used late in the fall in wet soil. In Georgia, propylene dichloride emulsion was more toxic to trees 4 years of age and under than ethylene dichloride, but serious injury occurred only when that material was applied around 2-year-old trees at the same strength and quantity as recommended for ethylene dichloride. The experiments indicated that good borer control without tree injury can be expected from propylene dichloride emulsion used at strengths from one-fourth to one-third lower than that required for ethylene dichloride emulsion, but further tests are needed to determine more definitely the strengths to be used on trees of different ages. In the comparative tests in Georgia paradichlorobenzene crystals were less effective than either propylene dichloride emulsion or ethylene dichloride emulsion in controlling the peachtree borer in peach trees 3 years of age or older, and the crystals caused serious injury to 1- and 2-year-old trees.—5-5-43.

DR. E. D. BALL

The death of Dr. E. D. Ball of the University of Arizona has recently been announced. Dr. Ball was a long-time member of the Association and served as its president in 1918. The *Journal* will print an adequate account of Dr. Ball and his accomplishments in an early issue.

The Viscosity and Thixotropy of Honey[1]

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The property of honey to thicken when cold is well known. Beekeepers usually refer to the thickness of honey as "body" and commonly judge the body of a honey by the time it takes an air bubble to rise through it when the containing vessel is inverted. This evaluation of body is assumed to indicate the degree of ripeness of the honey, but may prove unreliable unless the temperature of the honey at the time of testing is considered. Beekeepers have long known that honey is injured by excessive heating, hence it becomes a problem of practical importance to determine the temperature to which honey may be heated to reduce viscosity and thus to facilitate handling, and yet not to endanger its quality.

The tendency of honey to thicken when cold and to become thinner when warmed may be due to changes in viscosity, but the rise of an air bubble through it may also be modified by the tendency of some honeys to set on standing. Either or both physical properties have a marked effect on the methods suitable for use in preparing the honey for market, the rapidity and completeness with which the honey is extracted from the combs, the ease with which it is strained, and the facility with which it is poured into containers.

Honey from ling heather, *Calluna vulgaris*, becomes less mobile on standing, sometimes referred to as "jelling." This plant is found in various parts of the British Isles and the continent of Europe, but not to an extent in North America to serve as a source of honey. Ling heather honey sets so that it cannot be removed from the combs by centrifugal force unless the honey in each cell is disturbed just prior to extraction of the honey, and producers commonly separate this honey from the wax by pressing the combs. The setting of heather honey is not due to a low water content, since it usually contains a higher per cent of water than most honeys. After the honey is removed from the combs, it again stiffens upon standing and will not run out when the containing vessel is inverted. If the honey is slightly stirred, it flows freely but will set again. This is due to thixotropy, the name of a recognized physical property having been applied to this characteristic of heather honey by the Dutch chemists, de Boer & Kniphorst (1932).

While no honey produced in commercial amounts in the United States or in Canada shows this property of setting as markedly as does ling heather honey, such a property might be manifested in lesser degrees in other honeys. The suggestion has been made by Chataway (1932) that honey from buckwheat, *Fagopyrum esculentum*, produced in the region of shale-sandstone soils of the Allegheny Plateau of the northeastern United States and in eastern Canada may have this property in small degree. It is necessary to indicate the area where this honey is produced because buckwheat from other regions differs considerably from the buckwheat honey of the area indicated, not only in flavor and appearance but in physical qualities.

Previous Work.—Chataway (1932) demonstrates a close relationship between viscosity and absolute moisture content of honey, with the possible exception of buckwheat honey and honey which might be in an abnormal condition because of spoilage.

Paine *et al.* 1934 state that viscosity is decreased from 4.521 poises for normal buckwheat honey, to 4.214 poises for a corresponding sample with colloids removed; and for sumac, a honey of lesser colloid content, the viscosity showed a decrease from 3.686 poises for the normal sample, to 3.656 poises for the corresponding sample with colloids removed. In these tests both the buckwheat and sumac honeys, with and without colloids, were adjusted to 20 per cent moisture content, and the viscosity determinations were made at 45° C. They present no data on changes in viscosity with changes in temperature.

Scott-Blair (1935), reporting on the results of experiments conducted on heather honey, suggests that a test for thixotropy should prove of use in deciding whether excess water in honey is caused by unripeness or is normal owing to its heather

[1] Presented to the faculty of the graduate school of Cornell University, May, 1942, in partial fulfillment of the requirements for the degree of doctor of philosophy. An investigation conducted under the direction of Professor E. F. Phillips of Cornell University.

origin. Pryce-Jones (1936) reports having found that the removal of colloids from ling heather honey entirely eliminates thixotrophy. He also reports a peculiar physical property of ling heather honey which he describes as elastic recoil, thus indicating two types of thixotropy: the first, true thixotropy, which is a reversible gel-sol transformation and the second, which is defined as a partial disperson of a gel under the influence of shear and the re-formation of the gel on the removal of shear. Scott-Blair (1938) says of this, "since no system adheres strictly to the former definition it is doubtful if the distinction has any great significance."

Risga (1937), in discussing viscosity in relation to extraction, points out that heather honey and like honeys cannot be satisfactorily extracted but may be rendered by pressing, and illustrates a type of press used for the purpose. His article includes viscosity coefficient curves obtained on Latvian honeys which indicate viscosity reduction with rising temperature but fails to include supporting data.

MATERIALS AND METHODS.—Predominating floral sources of the honeys used in this work were aster, buckwheat, sweet clover, white clover, goldenrod, sage and heather, produced in the United States, except the heather honey which was obtained from England. Viscosities are measured by a MacMichael viscosimeter, which measures viscosity by the angular twist or torque of a standardized wire, and the measurements are readily transposed to poises.

The honey is placed in a cup of 3 cm. diameter and 5.3 cm. depth, and a plunger of 1 cm. diameter, suspended from the top of the instrument by a torsion wire, is lowered to a depth of 4 cm. into the honey in the cup. The cup which holds the honey is contained within an outer cup which serves as a water-bath for heating the honey to the desired temperature. The water-bath is warmed by a heating element which is activated through contact against the rim near the bottom of the cup, so that the honey may be heated while the apparatus is in operation. The cup revolves at a constant rate of 20 revolutions per minute. The amount of twist imparted to the wire is indicated on a graduated disc attached to the spindle, to the bottom of which the plunger is attached. The readings of the torsion wire are converted to poises by multiplying the degrees recorded on the viscosimeter by the conversion factor of each wire. The wires are standardized against a 60 per cent aqueous solution of sucrose (by weight) the viscosity of which is known.

The wires are 28 cm. in length but differ in diameter and consequently in torque resistance. They are designated by numbers corresponding to the Browne and Sharpe gauge. Only two wires are needed to cover the range of viscosities considered in this work, number 34 gauge (conversion factor of 5.55), and number 26 gauge (conversion factor of 240).

Temperatures are measured by a copper-constantan thermocouple junction inserted just below the surface of the honey. The junction measures slightly less than 2 mm. diameter. Its small size, coupled with the fact that it gives instantaneous response to temperature change makes this the only satisfactory method of recording for work of this nature.

PRECAUTIONS OBSERVED.—To insure dependable results it is necessary to make certain: (1) that the torsion wire is attached to the recording spindle of the viscosimeter at exactly the same height for each test; (2) that the viscosimeter is level; (3) that the cup rotates at a constant speed of 20 revolutions per minute; (4) that the thermocouple is in the same location in the honey for each test; (5) that the instrument is sheltered from drafts or side currents of air; (6) that the viscosimeter cup is always filled to the same level and covered, except when in operation, to prevent change in water content of the honey; (7) that the temperature and viscosity readings are made simultaneously; (8) that the least possible delay occurs when changing from one wire to the other; (9) that the honey is liquified without overheating and thoroughly mixed, without incorporation of air bubbles; (10) that each viscosity test extends over approximately the same period, seldom over 90 minutes and (11) that the temperature recording apparatus is balanced with the standard cell immediately prior to each test.

When it is desired to run viscosity tests at various levels of moisture content, the honey is prepared by adding distilled water to bring it to the maximum desired

moisture content. Lower moisture contents are obtained by warming the diluted honey to about 45° C., drawing off moisture under vacuum and removing portions of the sample, from time to time, as it becomes concentrated. Moisture determinations are made with a Zeiss Abbe refractometer.

Colloids in honey may be removed by diluting honey with an equal volume of distilled water, bringing the mixture to the isoelectric point of pH 4.3, incorporating a small quantity of finely divided diatomaceous earth, removing the precipitate by filtration and adjusting the filtrate to the original moisture content of the normal honey under vacuum.

Tests for thixotropy are made by use of the glass tube and falling ball apparatus described by Chataway (1932). The tube is of 16 mm. diameter, is clamped firmly in a vertical position, filled with liquid honey, and after remaining undisturbed for at least 24 hours, a spherical steel ball of 0.62 cm. diameter is lowered into it and allowed to settle to the bottom of the tube. The time required for it to drop through the honey a distance of 14 cm. is timed with a stop-watch and compared to the time required for the same operation directly after the honey is stirred. When the ball passes more rapidly through the freshly stirred honey, temperature remaining constant, than through the undisturbed sample, it denotes thixotropy of the honey.

EXPERIMENTS AND RESULTS.—Viscosities were determined over a wide range of temperatures, extending from as close to 0° C. as practicable to upwards of 80° C., which is higher than it is ever advisable to heat honey. Temperatures in degrees Centigrade and corresponding viscosities at the various levels of moisture content are given in the tabulations which follow. It is not practicable to control temperatures so that viscosity determinations can be made at temperatures in exact steps, and a better record is obtained by taking viscosity determinations and temperature readings simultaneously, at such intervals as are feasible. Summarization of viscosity changes with varying temperatures are presented in the accompanying figures (Fig. 1), from which intervening viscosities can readily be interpolated. The viscosity curves are so regular that it

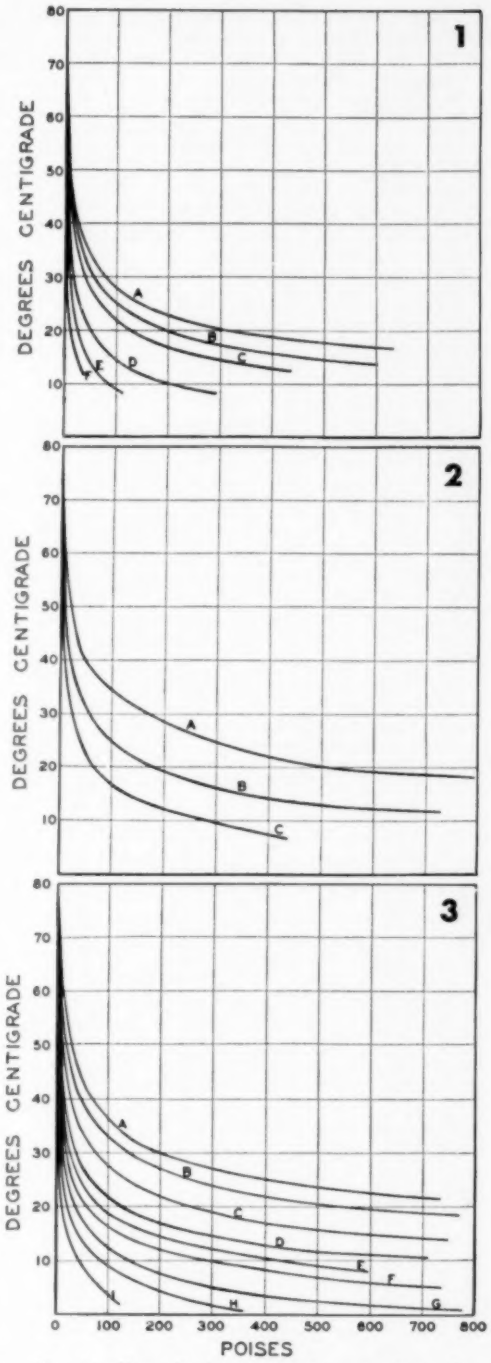

FIG. 1.—Viscosity in relation to percentage of moisture in honeys.
(1) Sweet clover honey. A. 15.4%; B. 16.1%; C. 17%; D. 19.4%; E. 20.8%; F. 24%.
(2) Sage honey. A. 14.6%; B. 16.6%; C. 18.6%.
(3) White clover honey. A. 13.7%; B. 14.2%; C. 15.5%; D. 17.1%; E. 18.2%; F. 19.1%; G. 20.2%; H. 21.5%; I. 24%.

Table 1.—Viscosity readings for different honeys at different temperatures.

Series 1 15.4 Per cent Sweet Clover		Series 2 16.1 Per cent Sweet Clover		Series 3 17.0 Per cent Sweet Clover	
°C.	Poises[1]	°C.	Poises	°C.	Poises
17.8	501.6	13.7	600.0	12.0	432.0
18.3	463.2	14.0	554.4	13.0	374.4
18.8	427.2	14.5	511.2	14.8	302.4
19.2	396.0	15.0	468.0	15.7	258.0
19.5	369.6	15.7	422.4	16.8	211.2
20.1	326.4	16.4	343.2	17.3	189.6
20.6	295.2	17.5	285.6	18.6	156.0
21.1	268.8	18.6	240.0	19.6	136.8
21.2	254.4	19.6	211.2	21.1	112.8
21.6	237.6	20.6	189.6	23.0	88.8
23.1	193.2	21.5	170.4	24.7	72.0
25.5	134.4	22.0	156.0	26.5	60.0
26.6	116.4	23.1	139.2	28.2	48.0
28.7	93.6	24.1	121.2	30.0	40.8
29.7	81.6	25.9	97.2	31.8	33.6
34.9	45.6	27.3	81.6	34.6	25.2
38.8	31.2	29.0	64.8	35.8	21.6
42.1	24.0	30.7	55.2	37.6	19.7
44.4	19.2	32.0	48.0	38.7	18.7
46.2	14.4	35.0	36.0	40.4	15.6
47.9	11.9	37.5	25.2	43.1	12.5
48.6	11.4	39.4	21.4	45.9	10.1
50.2	9.8	41.8	18.2	48.3	8.6
51.0	8.1	43.3	16.3	50.4	7.7
53.6	5.7	45.4	13.2	54.5	6.3
64.0	4.0	48.1	10.7	58.2	5.2
69.0	3.0	52.5	7.8	62.0	4.4
73.7	2.4	56.3	6.4	65.9	3.4
76.5	2.1	65.1	4.0	68.2	2.8
79.3	1.8	68.6	3.0	70.6	2.5
		71.1	2.6	73.4	1.9
		75.8	2.1	75.6	1.7
		78.5	1.7	77.9	1.4
		79.5	1.5	80.1	1.2

[1] Poise: The tangential force acting on one of two parallel planes, one centimeter apart each one centimeter square, so as to cause a velocity of one centimeter per second of the plane acted upon with respect to the other, the space being filled with the viscous substance.

Series 4 19.4 Per cent Sweet Clover		Series 5 20.8 Per cent Sweet Clover		Series 6 24.0 Per cent Sweet Clover	
°C.	Poises	°C.	Poises	°C.	Poises
8.1	288.0	8.3	110.4	11.7	37.8
8.6	259.2	9.1	104.4	14.0	25.4
9.0	242.4	9.6	93.6	15.1	21.8
9.8	213.6	10.1	84.0	16.2	19.0
10.5	196.8	10.6	76.8	16.9	17.4
10.8	177.6	11.0	72.0	17.5	15.8
11.6	158.4	11.7	66.0	18.6	13.6
12.1	146.4	12.0	62.4	19.9	11.8
13.1	124.8	12.7	57.6	20.2	11.6
13.5	117.6	13.7	50.4	20.5	10.9
14.5	104.4	14.6	44.6	21.3	9.9
14.8	96.5	15.1	42.7	23.4	8.4
15.5	91.2	16.0	38.4	25.9	6.9
15.9	84.0	18.7	30.0	32.4	4.3
16.3	79.4	20.2	26.4	53.0	1.3
16.8	74.2	21.5	23.7	56.7	1.0
17.4	69.6	22.9	20.4	60.4	.8
17.9	64.6	24.4	18.0	64.9	.6
18.4	60.0	26.5	16.3	70.8	.5
18.7	57.6	28.7	12.4	74.5	.4
19.7	50.4	30.8	11.7	75.0	.3
20.6	46.1	33.9	8.8	75.9	.3
21.7	40.6	35.2	8.1	77.9	.3
23.6	32.4	37.9	6.9	80.1	.2
26.7	23.5	39.7	6.1		
27.3	21.6	41.9	5.3		
28.5	18.7	44.0	4.5		
31.0	15.5	47.3	3.9		
34.9	12.4	50.8	3.1		
37.3	10.5	53.7	2.6		
41.7	8.0	57.0	2.0		
46.0	6.2	60.2	1.6		
51.5	4.5	62.7	1.4		
55.7	3.1	66.0	1.1		
60.8	2.2	69.8	.9		
65.8	1.6	73.2	.7		
72.2	1.0	77.2	.6		
79.3	.7	80.0	.5		

Series 7 14.6 Per cent Sage		Series 8 16.6 Per cent Sage		Series 9 18.6 Per cent Sage	
°C.	Poises	°C	Poises	°C.	Poises
18.1	787.2	11.7	729.6	6.0	434.4
18.4	760.8	12.0	667.2	6.8	400.8
18.7	732.0	12.2	631.2	8.9	331.2
19.0	696.0	12.5	595.2	9.5	297.6
19.2	648.0	12.8	566.4	10.9	249.6
19.5	602.4	12.9	542.4	12.1	208.8
20.1	547.2	13.5	494.4	13.0	177.6
20.4	506.4	13.9	448.8	14.0	148.0
20.7	477.6	14.2	420.0	15.4	120.0
21.6	422.4	14.6	393.6	16.2	105.6
22.8	376.8	15.1	357.6	17.6	91.2
23.9	331.2	15.8	315.6	19.2	72.4
26.3	261.6	16.2	295.2	20.1	64.8
27.7	220.8	16.8	271.2	22.4	52.8
32.3	129.6	17.3	252.0	24.0	45.6
34.1	105.6	17.9	235.2	26.4	37.2
36.2	81.6	18.8	216.0	29.1	28.8
37.6	69.6	20.2	184.8	31.9	22.1
39.4	52.8	21.6	153.6	36.2	15.6
40.8	43.2	23.4	122.4	40.4	9.7
43.3	33.6	25.9	88.8	42.6	9.0
45.6	26.4	27.8	69.6	44.4	8.2
51.7	18.7	30.7	55.2	46.1	7.3
55.0	14.4	32.1	45.6	48.2	6.5
57.1	10.7	34.0	38.4	53.4	4.8
57.9	9.9	36.2	31.2	55.8	3.9
60.0	8.3	38.8	24.0	57.2	3.4
62.1	6.9	40.9	19.2	59.3	2.9
67.4	5.0	42.0	16.4	62.2	2.5
73.9	3.4	44.1	14.8	64.7	2.0
75.9	3.0	45.7	13.0	72.1	1.4
78.6	2.6	48.0	11.5	74.1	1.2
80.9	2.4	50.7	9.3	77.0	1.0
		53.4	7.6	78.0	.9
		56.0	6.2	79.8	.8
		60.1	4.8		
		63.6	3.9		
		67.4	3.0		
		72.0	2.3		
		73.6	2.1		
		75.5	1.9		
		76.8	1.7		
		77.6	1.6		
		78.7	1.5		
		80.5	1.4		

Series 10 13.7 Per cent White Clover		Series 11 14.2 Per cent White Clover		Series 12 15.5 Per cent White Clover	
°C.	Poises	°C.	Poises	°C.	Poises
21.5	734.4	18.3	801.6	14.0	748.8
22.2	648.0	18.6	768.0	14.5	705.6
22.7	602.4	18.8	722.4	14.9	648.0
23.2	556.8	19.1	674.4	15.5	568.8
24.2	480.0	19.6	600.0	16.0	516.0
25.2	403.2	20.1	537.6	16.6	456.0
26.7	316.8	20.9	475.2	17.1	412.8
30.4	192.0	21.7	417.6	17.6	381.6
32.7	146.4	23.1	348.0	17.8	355.2
35.8	108.0	24.5	288.0	18.4	319.2
42.5	55.2	26.6	216.0	19.6	276.0
45.6	40.8	27.9	187.2	20.6	242.4
53.4	21.6	29.5	151.2	21.9	206.4
55.8	18.0	32.0	112.8	23.2	175.2
56.1	15.8	33.6	93.6	25.6	127.2
56.8	14.0	36.2	61.6	27.0	108.0
59.9	12.1	38.2	55.2	28.5	91.2
62.8	10.7	41.1	40.8	30.6	72.0
66.3	8.8	44.3	28.8	33.0	55.2
70.1	7.2	47.2	21.6	35.5	43.2
75.9	5.0	48.9	16.8	38.8	31.2
78.8	4.0	49.7	14.7	40.1	26.4
79.9	3.7	54.1	13.0	45.0	18.2
		58.7	10.3	47.5	12.5
		63.7	7.5	48.6	11.6
		71.5	4.6	50.1	10.4
		76.0	3.5	53.2	7.9
		77.9	2.9	55.6	6.7
		79.1	2.7	57.4	5.9
		79.8	2.5	61.0	4.8
				64.7	3.8
				66.8	3.3
				68.5	3.0
				71.0	2.5
				72.0	2.4
				74.2	2.2
				76.6	1.8
				77.6	1.8
				79.9	1.6

Table 1.—*Continued*

Series 13 17.1 Per cent White Clover		Series 14 18.2 Per cent White Clover		Series 15 19.1 Per cent White Clover	
°C.	Poises	°C.	Poises	°C.	Poises
8.3	782.4	8.9	528.0	4.9	736.8
10.8	681.0	9.8	468.0	6.4	564.0
11.5	600.0	10.9	403.2	7.5	468.0
12.0	542.4	12.1	340.8	8.7	384.0
12.6	487.2	12.8	300.0	10.0	300.0
13.8	376.8	13.4	271.2	11.2	228.0
14.5	333.6	14.2	237.6	12.6	177.6
15.0	292.8	14.8	208.8	13.9	144.0
16.0	247.2	15.8	170.4	16.3	96.0
16.8	216.0	16.8	144.0	17.1	84.0
17.3	194.4	17.6	122.4	17.6	76.8
18.2	165.6	18.3	108.0	18.7	67.2
19.0	148.8	19.1	96.0	20.4	55.2
20.2	122.4	20.1	84.0	22.2	45.6
21.8	103.2	22.0	67.2	24.7	36.0
23.7	79.2	23.3	57.6	27.6	26.4
26.0	61.2	25.0	48.0	31.3	19.2
29.5	44.4	28.6	32.4	34.1	14.4
31.7	30.0	30.8	24.0	40.5	8.8
36.7	19.2	34.5	18.7	41.8	8.0
38.5	16.2	36.8	15.1	43.3	7.0
44.1	12.4	40.0	12.0	45.5	6.1
44.7	12.1	41.6	9.8	47.9	5.3
46.9	10.5	42.8	8.6	51.7	4.3
50.4	8.8	43.3	8.2	55.1	3.4
53.2	7.2	44.5	8.0	60.0	2.6
58.0	5.2	45.7	7.5	64.1	2.0
61.7	3.9	47.1	6.8	68.8	1.5
68.2	2.4	49.7	5.8	71.1	1.4
70.7	2.0	51.8	5.2	73.2	1.2
74.8	1.5	56.5	3.7	76.0	1.0
75.5	1.3	60.1	3.0	80.0	.8
80.0	1.1	63.9	2.4		
		67.4	1.9		
		71.6	1.5		
		75.9	1.1		
		78.5	1.0		
		80.0	.9		

Series 19 18.6 Per cent Buckwheat		Series 20 20.8 Per cent Aster		Series 21 19.4 Per cent Goldenrod	
°C.	Poises	°C.	Poises	°C.	Poises
3.9	705.6	2.2	436.8	6.6	336.0
5.2	612.0	4.4	326.4	7.7	300.0
7.0	523.2	6.4	249.6	8.8	261.8
8.1	465.6	7.9	192.0	9.5	235.2
9.3	408.0	9.0	156.0	10.6	199.2
10.3	369.6	10.3	127.2	10.9	156.0
11.1	331.2	11.2	110.4	12.7	129.6
12.2	276.0	13.2	81.6	13.5	112.8
12.7	252.0	14.6	64.8	14.0	103.2
13.8	201.6	16.2	50.4	14.4	93.6
15.0	162.0	17.4	42.6	15.7	79.2
16.0	128.2	18.6	33.0	16.1	74.4
17.2	103.2	20.2	26.4	16.9	64.8
18.1	88.8	21.9	21.6	18.0	60.0
18.5	81.6	24.5	16.8	19.9	50.4
19.2	74.4	26.6	14.4	21.6	39.6
20.5	62.4	33.9	7.6	22.9	33.8
21.9	52.8	35.9	6.8	24.3	29.3
22.9	46.8	39.3	5.5	26.7	23.5
24.8	38.6	43.5	4.3	29.8	18.2
26.5	32.6	50.8	3.0	32.4	15.1
28.1	28.3	54.2	2.5	34.8	12.0
31.0	21.6	59.8	1.8	37.0	9.3
36.6	14.4	64.7	1.5	39.0	8.2
46.9	7.2	65.6	1.3	40.5	7.5
48.7	6.1	69.5	1.0	43.4	6.0
54.0	4.4	73.2	.9	46.7	4.9
58.0	3.4	74.9	.8	48.7	4.1
65.6	2.3	77.4	.6	52.4	3.2
66.9	2.0	79.9	.6	55.8	2.6
69.4	1.7			59.8	2.1
72.2	1.5			64.0	1.7
74.1	1.4			68.0	1.4
76.2	1.4			71.4	1.2
77.8	1.4			74.9	1.0
78.9	1.5			78.2	.9
79.6	1.5			80.4	.7

Series 16 20.2 Per cent White Clover		Series 17 21.5 Per cent White Clover		Series 18 24.0 Per cent White Clover	
°C.	Poises	°C.	Poises	°C.	Poises
0.9	768.0	0.7	352.8	2.2	120.8
1.4	711.6	1.6	321.6	3.4	108.0
1.7	655.2	2.3	283.2	4.3	99.2
2.2	592.8	3.2	249.6	5.3	88.0
2.5	542.4	4.0	223.2	6.4	76.8
2.8	504.0	4.8	196.8	7.0	71.2
3.2	451.2	5.5	175.2	7.7	64.8
3.7	403.2	6.6	146.4	8.4	58.0
4.2	350.4	7.7	124.8	9.5	48.0
4.7	304.8	8.4	112.8	10.2	44.0
5.2	273.6	9.7	91.2	10.7	39.6
5.9	232.8	10.8	74.4	12.2	31.2
6.3	206.4	12.2	60.0	13.5	25.2
8.4	180.0	13.8	49.2	14.2	22.8
9.1	165.6	14.9	43.2	16.8	18.0
9.7	153.6	15.8	34.8	18.2	15.6
10.8	127.2	17.9	28.8	20.9	12.4
12.3	105.6	19.3	25.2	22.6	11.6
13.8	84.0	24.8	13.9	24.7	9.3
14.5	76.8	26.9	12.4	26.1	8.2
15.5	64.8	27.2	12.0	28.3	6.9
16.9	52.8	30.7	9.7	29.6	6.4
18.3	45.6	34.4	7.7	33.3	4.9
21.8	28.8	39.6	5.3	38.4	3.8
26.4	18.7	48.3	3.2	41.7	3.0
34.2	10.0	55.9	1.9	46.9	2.3
36.6	8.8	61.1	1.4	47.5	1.8
37.1	8.2	65.3	1.0	54.1	1.4
38.8	7.4	71.2	.8	58.2	1.1
41.2	6.3	75.6	.6	62.8	.9
44.5	5.4	78.2	.5	66.2	.7
46.6	4.5	80.7	.4	67.7	.7
48.2	4.0			70.3	.5
49.8	3.5			72.8	.4
51.0	3.3			77.4	.3
55.4	2.7			80.0	.3
59.5	2.1				
63.4	1.7				
66.7	1.4				
70.5	1.1				
74.1	.9				
79.4	.7				
80.0	.7				

Series 22 20.8 Per cent Heather		Series 23 18.2 Per cent White Clover Colloids Removed		Series 24 18.6 Per cent Buckwheat Colloids Removed	
°C.	Poises	°C.	Poises	°C.	Poises
3.6	789.6	8.1	657.6	4.7	624.0
4.8	696.0	8.8	578.4	5.7	528.0
5.6	612.0	9.5	508.8	6.6	492.0
6.2	571.2	10.3	448.4	8.9	355.2
6.7	525.6	10.8	404.0	9.6	312.0
7.6	463.2	11.6	362.4	10.9	261.2
8.3	417.6	12.1	331.2	11.7	232.8
9.3	355.2	12.8	292.8	12.8	187.2
10.6	302.4	13.4	266.4	14.6	141.6
11.5	266.4	13.7	244.8	15.7	120.0
13.4	228.0	14.1	228.0	16.8	100.8
14.2	211.2	14.8	199.2	17.6	91.2
15.8	182.4	15.9	165.6	18.3	78.0
18.1	146.4	17.1	136.8	19.7	66.0
19.1	136.8	18.1	112.8	20.4	60.0
20.6	117.6	18.8	102.0	21.6	48.0
22.5	96.0	20.0	84.0	22.2	45.6
25.1	74.4	20.9	73.2	22.9	43.2
27.3	64.8	22.1	62.4	23.8	40.8
29.5	52.8	22.8	57.6	25.5	33.6
31.0	48.0	23.8	50.4	27.8	26.4
32.4	43.2	25.9	39.6	31.1	19.2
34.9	33.6	27.3	33.6	33.1	16.8
37.6	28.8	29.5	26.4	34.2	14.4
40.4	24.0	30.5	24.0	35.2	13.2
42.1	20.4	33.6	16.8	40.5	11.0
44.9	16.8	36.8	15.1	44.1	8.8
47.6	13.5	42.4	10.3	47.5	6.5
48.3	12.8	43.3	9.8	50.4	5.2
50.5	10.9	44.3	9.2	55.7	3.8
51.4	10.0	45.8	8.3	60.1	2.7
52.4	9.0	48.4	6.8	65.0	2.0
57.3	7.9	52.1	5.5	73.6	1.0
60.0	7.4	55.4	4.4	76.5	.9
64.5	6.4	57.9	3.8	78.5	.8
66.3	6.5	61.3	3.1	80.0	.7
68.5	6.7	62.8	2.7		
70.9	7.0	66.3	2.1		
73.9	7.5	70.2	1.7		
76.9	7.7	73.3	1.4		
78.9	7.8	76.7	1.1		
83.1	7.9	78.1	1.0		
89.8	9.6	79.9	.9		

Table 1.—*Continued*

Series 25 20.8 Per cent Heather Colloids Removed		Series 26 18.6 Per cent Buckwheat Overheated		Series 27 19.4 Per cent Sweet Clover Fermented	
°C.	*Poises*	°C.	*Poises*	°C.	*Poises*
1.7	468.0	7.6	756.0	3.9	432.0
3.5	384.0	8.8	672.0	5.5	369.6
6.1	283.2	9.5	600.0	6.9	307.2
7.2	235.2	10.0	549.6	8.5	259.2
8.8	187.2	10.5	499.2	9.8	208.8
9.7	158.4	11.5	420.0	12.7	144.0
11.2	120.0	12.0	384.0	14.5	110.4
12.3	100.8	12.8	331.2	14.9	93.6
13.4	86.4	13.7	283.2	15.6	81.6
14.6	69.6	14.5	247.2	17.2	64.8
15.4	62.4	14.9	230.4	18.9	48.0
16.2	55.2	15.4	220.8	21.5	43.2
17.2	48.0	15.9	204.0	22.5	28.8
18.1	40.8	16.3	192.0	23.2	26.4
19.2	36.0	17.2	170.4	27.1	20.5
20.1	31.2	17.9	153.6	28.6	18.6
20.8	27.6	21.0	108.0	31.3	15.8
21.6	25.2	23.3	86.4	32.8	14.4
22.3	24.0	25.1	72.0	34.2	12.9
23.3	21.6	26.8	62.4	35.2	11.9
24.9	19.7	30.2	45.6	37.0	10.2
25.6	18.3	32.2	38.4	38.5	9.3
26.6	17.1	34.1	31.2	40.7	7.8
27.7	16.0	39.0	21.6	42.9	6.8
28.9	14.6	45.4	11.2	45.7	5.7
29.7	13.8	46.8	10.6	50.5	4.5
31.0	12.6	48.1	9.9	55.9	3.7
33.5	10.8	53.2	7.6	61.4	2.9
35.8	8.8	54.7	6.7	64.3	2.2
44.3	5.5	57.3	5.9	66.3	1.9
47.7	4.5	62.5	4.7	68.3	1.7
50.9	3.6	65.7	3.9	73.9	1.1
53.7	2.9	68.9	3.3	77.8	.9
56.5	2.5	72.2	2.7	79.0	.8
59.4	2.1	74.2	2.5	80.2	.8
62.6	1.8	75.9	2.3	84.0	.7
65.8	1.4	77.5	2.1	85.1	.7
68.6	1.3	79.2	2.0	86.1	.7
70.9	1.0	80.7	1.9	87.7	.6
73.9	1.0	82.4	1.9	88.9	.5
76.9	.9	83.8	1.9		
79.6	.8	86.7	1.9		
84.1	.7	89.6	1.8		
85.2	.6	92.1	1.8		
88.0	.5	39.8	1.7		

seems important also to present the tabulations, to justify this regularity. (Table 1.)

SIGNIFICANT RESULTS.—Examination of the foregoing data shows an inverse relationship between temperature and moisture content to effect similar viscosity as expressed in measurements which give the same value in poises for each change of one per cent in the moisture content of the honey, as follows:

Table 2.—Relation between effects of temperature and moisture on condition of different honeys.

POISES	100	200	300	400	500	600	700
	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Sweet Clover	3.1	3.4	3.4	3.6	4.5	4.5	—
White Clover	3.1	3.3	3.2	3.3	3.3	3.2	3.2
Sage	4.2	4.2	3.7	3.6	3.6	3.5	3.4

Average: 3.51° Centigrade

This inverse relationship held fairly constant for room temperatures and continuing on down to the lowest temperature points to which measurements were carried. The data indicate that for each one per cent decrease in moisture content of the honey there is required a corresponding increase of approximately 3.5° Centigrade to effect similar viscosity.

THIXOTROPY.—All honeys tested for viscosity were also examined for thixotropy. The detailed information, including moisture content, color number, room temperature where work was done, and the number of seconds required by the ball to pass through each honey, both before and after stirring, is summarized in table 3.

Table 3.—Time in seconds taken by a steel ball to drop through 15 cm. honey.

HONEY,[1] PER CENT MOISTURE	COLOR NUMBER	°C.	BEFORE STIRRING	AFTER STIRRING	THIXOTROPY[2]
Aster	8.0	22.7	10.2	10.2	
20.8		23.0	9.2	9.2	None
Buckwheat	11.7	20.0	31.6	29.2	
18.6		20.1	31.2	27.8	
		24.0	21.2	18.4	Slight
Buckwheat	8.2	19.8	34.4	34.4	
Colloids removed		24.0	20.6	20.4	None
18.6		27.0	13.4	13.4	
Buckwheat	13.9	23.0	37.8	35.6	
Overheated		25.0	29.8	27.6	
18.6		27.5	19.6	18.6	Slight
Sweet Clover	0.9	22.0	41.6	41.2	
17.0		25.1	28.2	27.6	Trace
Sweet Clover	0.9	18.5	15.8	15.6	
Fermented		20.0	11.8	11.4	
19.4		28.0	5.6	5.6	Trace
White Clover	1.5	23.0	24.0	24.0	
18.2		27.0	14.2	14.4	None
Goldenrod	9.1	21.0	18.4	18.4	
19.4		28.0	8.4	8.4	None
Sage	0.6	26.8	32.4	32.4	
16.6		27.0	31.6	31.4	None
Heather	14.0[3]	22.0	1323.4	29.0	
20.8		24.0	580.4	20.6	High
Heather	10.5	27.0	14.0	12.2	
Colloids removed		28.0	11.0	10.8	Trace
20.8					

[1] Normal honey unless otherwise indicated.
[2] The physical property of the honey to become more fluid when shaken or stirred. The change is reversible.
[3] This is darker than usual for heather honey. The sample was about five years old when tests were made. Other honeys used, less than one year old.

DISCUSSION.—There is close similarity in the changes of viscosity with temperature for the different honeys. As cold honey is warmed it undergoes the greatest decrease of viscosity with rising temperature. This is indicated by the nearly horizontal portion of the curves extending from the readings nearest the freezing point of water and approaching room

temperature. Further warming is characterized by a rapidly changing rate of viscosity decrease as shown by the increasingly upward trend of the curves to a point where the changing rate practically ceases and the viscosity is sufficiently reduced for efficient handling of the honey. For a honey of average moisture content this occurs at about 30° C.

Further decrease of viscosity with rising temperature, as indicated by the nearly vertical curves, is so meagre as to be of no practical significance and heating to higher temperatures would not be required except as might be necessary for melting crystals of granulated honey or the destruction of included yeasts.

Honey, then, undergoes three successive stages of decreasing viscosity with rising temperature. The first stage begins as cold honey is warmed and represents the most extensive decrease of viscosity per degree rise. It is followed by the second stage which consists of a rapidly changing rate that practically terminates as the honey becomes sufficiently reduced in viscosity for efficient handling. The final stage is represented by meagre decrease in viscosity with further rise of temperature and is of no significance in practice.

The temperature which marks the termination of rapid change in viscosity rate indicates the upper limit to which honey should be warmed for efficient handling. For a honey with high moisture content of 20.2 per cent, as represented in the chart for white clover honey, this rapid decrease in viscosity rate terminates at about 20° C., while for honey with exceptionally low moisture content of 15.5 per cent this occurs at about 36.5° C. Since the changes in rate of honey viscosity are relatively great below these temperatures, the test for "body" of allowing an air bubble to rise through honey when the containing vessel is inverted becomes worthless and misleading. Since the rapid viscosity changes occur so near to ordinary room temperatures the usefulness of this common method for testing the body of honey becomes still more unreliable. As the percentage of moisture in honey increases, warming to put it into condition for efficient handling is less important.

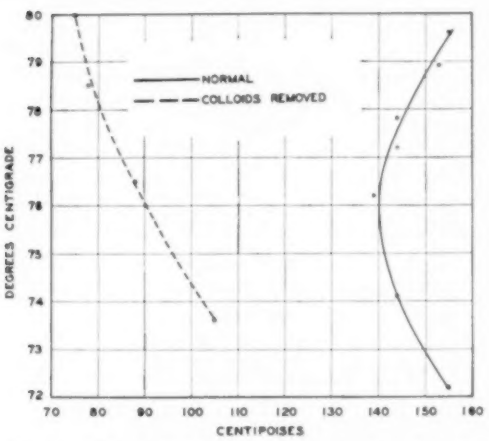

FIG. 2.—Effect of high temperature on the viscosity of buckwheat honey. The honey was of 18.6 moisture content.

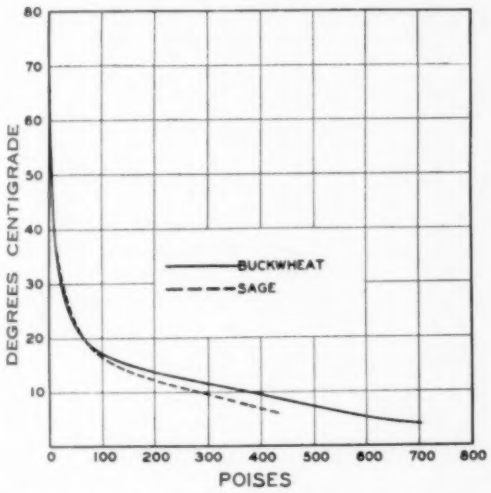

FIG. 3. A comparison of the viscosities of buckwheat and sage honeys of 18.6 per cent moisture content.

The temperature to which honey must be warmed to bring about the necessary reduction of viscosity is then inversely proportional to its moisture content. For each one per cent decrease in moisture content of honey there is required a corresponding increase of approximately 3.5° C. to effect similar viscosity. This relationship remains fairly constant as the honeys are warmed to the point for satisfactory handling.

Honeys of similar moisture content but of different floral origin vary to some extent in viscosity at any given temperature but the variations encountered, with the exception of heather honey, were not sufficient to be of practical concern in the handling of honey. This point may be

illustrated by comparing the viscosities of honeys of similar moisture content, such as buckwheat and sage of 18.6 per cent; sweet clover and goldenrod of 19.4 per cent; sweet clover, aster and heather of 20.8 per cent; and sweet clover and white clover honeys of 24.0 per cent. The widest variation and the only one of practical significance is for heather honey which shows from three to four times the viscosity to be found in either aster or sweet clover honey of similar moisture content. The difference in behavior with regard to changes in viscosity of honeys at any given moisture content may be due to a variety of factors, such as colloid content, ratio of one kind of sugar to another and perhaps to a lesser extent the presence of other substances.

EFFECT OF OVERHEATING.—Buckwheat

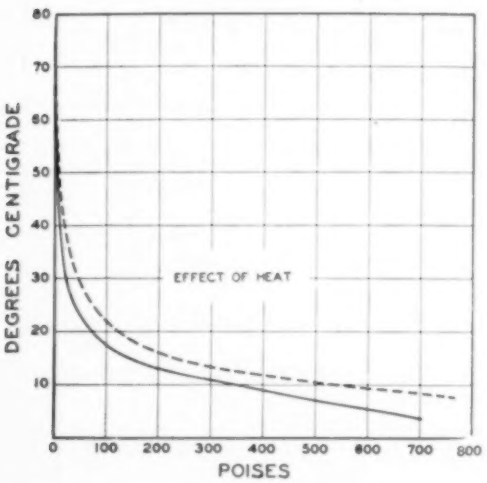

FIG. 4. Permanent increase in viscosity caused by overheating. The solid line represents the viscosity of buckwheat honey of 18.6 per cent moisture which had not been heated prior to the test, and the dotted line represents a corresponding sample of buckwheat honey which was heated to 80° Centigrade, held at this temperature for one hour, and cooled prior to making the test.

honey is exceptionally sensitive to overheating and beekeepers are aware that they can heat clover honey with less danger than buckwheat honey. Slight overheating of buckwheat honey causes foaming and seriously damages the flavor, giving it a burned taste. An even more noticeable change is that buckwheat honey, already opaque, becomes still more opaque on overheating.

The effect of colloids on viscosity was determined by running tests on white clover, buckwheat and heather honeys before and after removal of colloids. In removing the colloids from these honeys it was observed that the colloidal precipitate varied greatly, white clover having only a slight amount, buckwheat somewhat more, and heather honey a relatively large amount. This is in agreement with the findings of Paine *et al.* (1934) who showed that white clover contains 0.18 per cent colloids and buckwheat 0.80 per cent. Pryce-Jones (1936) found that the colloidal precipitate of heather honey is about 30 times that of clover honey. Such variation in the colloidal contents of these honeys would explain the differences between the viscosity of the normal heather honey and the heather honey with colloids removed, the closer agreement of the buckwheat honey, with and without colloids, normally of lesser colloid content, and the virtual similarity in viscosity of white clover honey, with and without colloids, and supports the theory that colloids have a marked effect on viscosity.

There is a pronounced tendency for heather honey to change from a decreasing viscosity to an increasing viscosity with rising temperature, after it has reached 64.5° C. Buckwheat honey behaves in a similar manner when it has reached 76.2° C. This change is probably due to the action of heat in coagulating the colloids, inasmuch as (1) the increasing viscosity terminated when the action of the heat had completed the coagulation of colloids, and (2) this did not occur in honey with the colloids removed. The increased viscosity brought about by overheating produced a lasting physical effect on honey, since when honey is tested for viscosity, over a long range of temperatures, after overheating, it shows a higher viscosity throughout the entire range of temperatures. After the colloids are coagulated by heat, such honey does not show a tendency again to change from decreasing to increasing viscosity at high rising temperatures. One of the first outward signs preceding the tendency for the honeys to change from decreasing to increasing viscosity, with high rising temperatures, is foaming. Foaming begins a few degrees below the point at which this change in viscosity is indicated and continues until coagulation of the colloids is complete.

Heather honey which has the highest colloid content shows a pH reaction of 4.3 and, being already at the iso-electric point, does not require adjustment of pH to bring about precipitation of colloids. Buckwheat honey, of indeterminate colloid content, has a pH reaction of 3.8, and white clover honey, with the lowest colloid content of the three, has a pH reaction of 3.6.

Fermentation has no significant effect on viscosity, since viscosity tests on normal sweet clover honey of 19.4 per cent moisture, and of a corresponding sample of fermented sweet clover honey of similar moisture content gives similar results.

That colloids are an important factor in inducing thixotropy of honey is indicated by the fact that thixotropy is eliminated when colloids are removed, as pointed out by Pryce-Jones, 1936, for heather honey. Buckwheat honey is only slightly thixotropic, and sweet clover honey shows only a trace of thixotropy. To what extent change of temperature affects thixotropy is not entirely clear although for heather honey a lowering of the temperature from 24° C. to 22° C. resulted in the steel ball requiring more than double the time to pass through 14 cm. of honey that had remained undisturbed for the preceding 24 hours prior to making observations. From this it would appear that change in temperature has a profound effect on thixotropy, particularly in a highly thixotropic honey such as heather. Overheating or fermentation has no significant effect on thixotropy as indicated by the tests on buckwheat and sweet clover honeys.

CONCLUSIONS.—The data in this paper lead to conclusions of practical significance in the preparation of honey for market. The chief conclusions are as follows:

(1) That the greatest decrease in viscosity per degree rise occurs as cold honey is being warmed toward room temperatures. Further warming results in a rapidly changing rate or modification of viscosity which practically terminates as the viscosity becomes sufficiently decreased for efficient handling. This occurs at about 30° C. (86° F.) for most honeys. Further heating results in such slight decrease of viscosity per degree rise as to be without practical significance.

(2) That, up to the point where honey must be warmed for efficient handling, for each one per cent decrease in moisture content of honey there is required a corresponding increase of approximately 3.5° C. to effect similar viscosity.

(3) That while honeys of similar moisture content but different floral origin vary with respect to viscosity changes, the variations encountered, with the exception of heather honey, are not sufficient to be of practical importance.

(4) That, since the changes in rate and degree of viscosity are relatively great at ordinary room temperatures and below, the common test for "body," of allowing an air bubble to rise through honey when the containing vessel is inverted, is misleading.

(5) That overheating which results in coagulation of the colloids, darker color, and burned flavor of honey, causes a permanent increase in viscosity.

(6) That there is a direct relationship between colloid content and the extent of thixotropy and increased viscosity of honey.

(7) That fermentation has no significant effect on the viscosity or thixotropy of honey.—5-2-43.

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Larval Food and Development of Castes in the Honeybee[1]

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"One of the most essential and the most typical characterization of social insects is the existence of the two kinds of females: the females proper, which assure the continuation of the species and the sterile, or neutral females which provide the food for the larvae and perform all kinds of home duties" (Vendel 1930).

The queen of the honeybee is concerned only with the egg laying and she is the only fully developed female in the colony. The workers constitute the bulk of the population and provide for the well-being of the bee community, feeding larvae, cleaning the hive, performing duties, bringing and storing nectar, pollen and water, etc.

The larvae of the honeybee are fed a special food. It is a paste-like substance with the consistency and color of condensed milk, strongly acid and having a distinct aroma. There has been considerable controversy as to the origin of this food. Schönfeld, thought it to be a regurgitated product of the stomach digestion, while Fisher believed that this food originates in the salivary glands of the head and the thorax. Serological investigations of Langer (1912) proved it to be the product of the pharyngeal glands, located in the heads of bees. For the review of this question the reader is directed to the articles of Planta (1888), Langer (1929) and Elser (1929).

Comparatively few chemical analyses of the larval food are available. Planta (1888, 1889) investigated the chemical composition of the food of the queen, worker and drone larvae. The material for the investigation was supplied by beekeepers. The results of his analysis are shown in table 1.

Table 1.—Chemical composition of larval food (Planta).

	Queen	Worker		Drone	
		Under 4 days old	Over 4 days old	Under 4 days old	Over 4 days old
	Per Cent				
Protein	45.14	53.38	27.87	55.91	31.67
Fat	13.55	8.38	3.69	11.90	4.74
Glucose	20.39	18.09	44.93	9.57	38.49

According to Planta, larval food of the queens, worker and drone larvae during the first four days of their lives contained only traces of pollen or none at all. However, the food of the older drone larvae had a great admixture of pollen (15,000 pollen grains in a milligram of food), while the food of the older worker larvae was pollen free. Moreover, there was a distinct change in the composition of the food of the worker and drone larvae after they attained the age of four days. Nevertheless, if we take the averages of the composition of food for the whole period of feeding and compare them with the composition of the food of the queen larvae, then the differences are not so striking. Since the examination of the larval food from the queen cells was not according to the age of the queen larvae, one cannot rightly assume that there is not a change in the diet of the queen larvae similar to that of the worker larvae.

Planta concluded that the bees prepare larval food according to the nutritional purpose (Nährzweck) which it has to perform. He believed the fact that the composition of the larval food was not constant supported Schönfeld's theory of its origin. Higher sugar content of the food of larvae over 4 days old, according to Planta, was due to the addition of honey to the food. He thought that honey was swallowed by bees, admixed to the larval food in their stomachs, and then fed to larvae. He stated, however, that a better nourishment of the queen larvae, as compared with that of the drone and worker larvae, no doubt was achieved mainly by the greater quantity of food which the former receive.

There was no record of any chemical analysis of larval food until Köhler (1922) tried to verify Planta's findings. She ques-

[1] Paper No. 2091 Scientific Journal Series, Minnesota Agricultural Experiment Station, St. Paul, Minnesota.

[2] The author is grateful to Dr. W. A. Riley and Dr. M. C. Tanquary for their helpful suggestions during the preparation of the manuscript and to Mr. A. E. Vivino for the analyses of the larval food.

tioned the correctness of the assumption that the food of over-four-days-old worker and drone larvae is changed, because, even if one may agree that the bees can recognize the age of the larvae, it is scarcely possible that they can voluntarily change the composition of the food produced in their glands.

Köhler's analyses of the food of under-four-days-old larvae showed that the fat content was 23.3 and 24.23 per cent and the sugar content 15.7 and 14.9 per cent for the worker and drone larvae respectively. The differences which she obtained were in the limits of experimental error. According to Köhler, it is only after 4 days of age that the larvae of both drones and workers receive an admixture of pollen and honey. However, she did not state the source of her information.

Nelson & Sturtevant (1924) observed that the change in the diet of worker larvae takes place as early as during the third day. Undigested pollen grains were regularly found in the food of larvae no more than three days old from the time of hatching from the egg, often in a sufficient amount to color the food slightly.

Royal jelly examined by Aeppler (1922) contained 24.15 per cent moisture. Of the dry matter 30.62 per cent were proteins, 15.22 per cent fat, 14.05 per cent sugars and 2.3 per cent ash.

Elser (1929), using microchemical methods, made a very thorough investigation of the food of queen larvae. The material was supplied by beekeepers and seven to fifteen milligrams were used for one determination. He investigated the larval food in consecutive days of feeding, from the second to the seventh, inclusive. The average results are presented in table 2.

The table shows that there was a decrease in the percentage of proteins in the food after the larvae passed their second day of life. Planta observed such a decrease for the worker and drone larvae. There was an increase in the percentage of invert in the diet of queen larvae; this fact was also observed by Planta in the case of drones and workers. There was a considerable decrease in the dry matter of the food. Apparently the amount of nutrients in the larval food per volume intake was lower in over-two-days-old larvae than that in the younger larvae. Elser always found pollen grains in the food of queen larvae, partly unbroken, partly broken. Quantitatively, there was always the same amount, regardless of the source. He believed that the pollen was added mechanically.

Table 2.—Percentage composition of food of queen larvae (fresh matter).

AGE	WEIGHT OF LARVAE	WEIGHT OF FOOD	MOISTURE	DRY MATTER	PROTEIN	FAT	INVERT	pH
2 days	2.0 mg.	20.0 mg.	50.7	49.3	18.9	8.6	11.2	4.6
3	4.3	142.3	58.7	41.3	10.4	4.9	8.3	4.8
4	23.1	282.2	62.8	37.2	10.1	6.0	9.5	4.7
5	91.3	307.0	65.6	34.4	9.4	4.2	11.2	4.8
6	148.7	298.8	62.2	37.8	9.0	4.3	10.2	4.5
7	295.5	384.2	56.3	43.7	10.6	2.6	13.8	4.1

By the determination of pH, Elser found an additional proof of the origin of the larval food from the pharyngeal glands, because pH of the stomach, according to his determinations, was 5.6, 6.0, 5.8, 5.9 and 6.3.

The weights given for the young queen larvae in the table of Elser are so low as to suggest that mistakes in the determination of the age of larvae had been made by the beekeepers who supplied the material. Melampy & Willis (1939) give the average fresh weight of 4–5 day old larvae as 133 mg. At the University of Minnesota apiaries we have not found the weight of four day old queen larvae dropping below 123 mg.

Melampy & Jones (1939) made a chemical analysis of royal jelly taken from the cells containing larvae between 3 and 4 days old. They found that the royal jelly is of remarkably constant chemical composition and the average results (8 samples) of their analyses showed it to contain 66.05 per cent water, 39.95 per cent dry matter, 12.34 per cent protein, 5.46 per cent fat, 12.49 per cent reducing sub-

stance, 0.82 per cent ash and 2.84 per cent undetermined matter.

During the season of 1942 a study of the changes in the composition of royal jelly and the food of worker larvae was made at the University of Minnesota. The royal jelly was taken from the swarm cells, according to the age of the queen larvae and the food of 1, 2, 3, 4, 5, day old and just sealed larvae was stored separately in a refrigerator. The age was determined by the size of the larvae.

Because the amount of larval food supplied to worker larvae is extremely small—1.7 and 1.9 mg. per cell, according to Planta (1888) and Aeppler (1922) respectively, the food from the cells containing hatched to 2 day old larvae was combined in one sample. The food taken from the cells with 3 to 5 days old larvae formed another sample. The analyses were performed by A. Earl Vivino, graduate student in the Division of Agricultural Biochemistry, University of Minnesota.

The results of the analyses are presented in table 3.

It is apparent from the table that the dry matter, on the whole, diminishes in the food of older queen larvae while the protein and fat content in the fresh matter increases, and the amount of mineral matter decreases. This is not in agreement with the findings of Elser. The results of the analysis of the food supplied to worker larvae also differ numerically from those of Planta, but the general tendency is the same. The protein and the fat contents decrease in the food of the older larvae. However, there is no such striking difference between the food of older worker larvae and that of the queen larvae as indicated by the findings of Planta. The protein content in Vivino's analyses is just as high or even higher than that of royal jelly while the fat and the ash contents are lower than those in the food of older queen larvae of the same age. The food of the younger worker larvae is richer in protein and fats than that of 1 to 2 day old queen larvae, the mineral matter being present in about the same proportion. It should be noted, however, the percentual composition of larval food actually may be somewhat different, because some water may have evaporated from food. Although for obtaining food,

Table 3.—Chemical composition of the larval food of female honeybees.

Age of Larvae Days	Moisture	Dry Matter	Nitrogen	Protein N×6.25	Fat	Ash	pH
			Per cent in fresh matter				
Royal jelly							
1	65.37	34.63	2.24	14.00	2.63	1.19	4.15
2	69.17	30.83	2.41	15.06	1.73	0.91	4.10
3	69.88	30.12	2.44	15.25	4.86	0.79	4.20
4	69.70	30.30	2.24	14.00	5.68	0.70	4.15
5	67.58	32.42	2.58	16.13	4.92	0.76	4.19
Sealed	68.32	31.68	2.94	18.38	3.99	0.75	4.15
Larval food of workers							
1–2	73.51	26.49	3.32	20.75	4.69	1.07	4.00
3–5	64.90	35.10	2.83	17.69	2.06	0.58	3.90
			Per cent in dry matter				
Royal jelly							
1			6.47	40.43	7.59	3.34	
2			7.82	48.85	5.61	2.95	
3			8.10	50.63	16.13	2.63	
4			7.39	46.20	18.74	2.31	
5			7.93	49.75	15.18	2.34	
Sealed			9.28	58.01	12.59	2.37	
Larval food of workers							
1–2			12.53	78.33	17.70	4.04	
3–5			8.06	50.39	5.87	1.65	

the larvae were removed only from 2 to 3 rows of cells at a time, the total procedure of taking larval food from the whole comb has taken between 3 to 6 hours. The pH of the larval food is markedly lower than that of the royal jelly.

The microscopical pollen count in the food of the younger worker larvae showed, on an average, 6 grains per unit of the visual field, while 11 grains were found for the same area in the food of 3 to 5 day old larvae (average of 60 counts for 12 samples in each case). There were only traces of pollen present in royal jelly fed to the queen larvae of different ages. The fact that some workers (Planta) did not find pollen in the larval food of female honeybees, some in small amounts (Elser), others in considerable amounts (Nelson & Sturtevant, Köhler, Rhein) suggests that the admixture of pollen to the larval food is accidental and not essential for the production of workers. This assumption is further supported by the demonstration that adult bees can produce workers when supplied only a sugar solution, thus utilizing the stores of their own bodies for the synthesis of the larval food (Haydak 1935), or when fed a number of pollen substitutes given in liquid or in a honey-paste form (Haydak 1933).

The discrepancies with the findings of Planta were manifested in some previous analyses of the larval food of honeybees. In his preliminary investigation Langer (1929) obtained different data on the composition of larval food from those either of Planta or Köhler. He considered that the larval food does not have any fixed composition but is in certain limits variable, and that the growth of the brood is affected by such variations. Elser fully agrees with this statement of Langer. Although he has no doubt that the work of Planta represents a milestone in the investigation of the chemical composition of the larval food, Elser does not consider the data to be strictly correct, due to some objections in the methods employed. Langer (1929) stated that "Data given by Planta do not represent formulas of larval food, but are only to be considered as the results of one investigator." The fact that all the materials in the investigations of Planta and Elser were supplied by beekeepers who might not have taken the necessary precautions to avoid error should also be noted.

Recently Townsend & Lucas (1940a) started a thorough investigation of the chemical composition of royal jelly taken from the bottoms of queen cells containing larvae 2–3 days old. The moisture content of the samples varied from 45 to 65 per cent. The dried matter has been separated into four main fractions:

Fraction I (Ether soluble, 10–15 per cent of dried powder) contained 4–10 per cent phenols, 80 to 85 per cent unidentified acids, 3 to 4 per cent sterols and glycerids, 5 to 6 per cent wax, and 0.4 to 0.8 per cent phospholipids.

Fraction II (water soluble and dialysable, about 55 per cent of the dried royal jelly) contained 1.2 per cent N, 3.4 per cent ash and about 50 per cent reducing sugars, of which 52 per cent were fructose, 42 per cent glucose and 6 per cent nonfermentable matter. About 20 per cent of the fraction consisted of an unidentified acid.

Fraction III (water soluble, nondialysable, 15 to 20 per cent of total dry matter) was found to contain 0.5 per cent ash, 14.9 per cent N, 0.3 per cent P and 0.89 per cent S. Qualitative tests for tryptophane, tyrosine, cystine and arginine were positive; the test for histidine was faintly positive. The nitrogen distribution was as follows (15.0 per cent N, on moisture and ash-free basis): Melanin N—less than 1 per cent of total N; ammonia N—13 per cent, dicarboxylic acid N—10 per cent; basic N—21 per cent; non amino N—20 per cent and mono-animo N—35 per cent of total N. Aspartic acid (9.9 per cent,) arginine (10 per cent) and tyrosine were isolated.

Fraction IV (water insoluble protein, 15 per cent of dried royal jelly) contained 13.4 per cent N and 0.16 per cent P, also S. Tests for tyrosine, tryptophane and arginine were positive.

An earlier study of N distribution by Aeppler (1922) showed the protein fraction to consist of 76.37 per cent of non-basic N, of which 59.49 per cent was amino N, 5.16 per cent ammonia N, and 3.23 per cent humin (melanin) N. The basic N constituted 14.23 per cent of which 9.51 per cent was basic amino N, 1.74 per cent histidine N, 4.41 per cent lysine N, 3.28 per cent cystine N and 4.77 arginine N. The material was fairly rich in basic N and very rich in cystine. It also contained tryptophane and tyrosine.

Melampy & Jones (1939) established the digestion coefficient as 81 per cent and the average biological value of royal jelly protein 75 per cent (which compares favorably with Mitchel's value for beef protein 69 to 77 per cent).

The investigation of Abbott & French (1940, 1941) indicated that the protein of royal jelly consists of two major components, one evidently a globulin and another an albumin. These are present in the proportion 1:2. According to the same authors, about one-half of the ether soluble matter of royal jelly consists of a fatty acid not previously reported in the literature with an empirical formula of $C_{10}H_{18}O_3$, which would indicate a saturated ring structure.

Heyl (1939) made an observation suggesting the presence of a gonadotropic hormone in royal jelly. A pyridine extract injected for five days into 21 day old rats in the amounts equivalent to 60 to 700 mg. of natural royal jelly was attended by a precocious development of the Graafian follicles. The degree of the response was directly proportional to the strength and to the amount of the extract used. Abbot (1939) also demonstrated the presence of an oestrogenic hormone in royal jelly by injecting an extract of the latter into spayed rats. Melampy & Stanley (1940) could not find any changes in the rats receiving the pyridine extract of acetone-dried royal jelly as compared with the controls. From their preliminary assays they concluded that a substance which causes follicle stimulation in the white rat is not present in the royal jelly of the honeybee. They remarked, however, that more detailed work may demonstrate the presence of a gonadotropic substance which may or may not be associated with caste production in the honeybee. Townsend & Lucas (1940b) by some feeding experiments revealed that the ether-soluble fraction of royal jelly possessed a remarkable influence on the number of eggs laid and the rate of reaching sexual maturity in the fruit fly, *Drosophila melanogaster*. They suggested that the failure of Melampy & Stanley to confirm Heyl's results was due possibly to the fact that the former used royal jelly dried by acetone which process would have removed also sterols and other constituents some of which are the very types of compounds most likely to show gonadotropic activity.

In her study of royal jelly, Abbott (1939) found that it has remarkable keeping properties, which she explained is due in part to the high concentration of sugars augmented by the presence of a fatty acid which has antiseptic activity. McCleskey & Melampy (1939) demonstrated that royal jelly possesses definite bacteriostatic and bactericidal properties. The active principle in royal jelly was not filterable through paper and was found in the sediment on centrifugation. Autoclaving at 120° C. for 20 minutes did not destroy the germicidal principle. The active principle was removed from royal jelly by extraction with alcohol and aceton. From these extracts were obtained crystals which appeared to possess the germicidal principle.

While studying the chemical composition of royal jelly, Aeppler (1922) found by a biological assay that royal jelly contains considerable quantities of water soluble B vitamin. The fat soluble vitamin A was either lacking or present in only small amounts.

The fact that the queen bee, which is abundantly fed royal jelly during the active season, may lay up to 2000 eggs in a single day aroused a belief that royal jelly is rich in vitamin E. Hill & Burdett (1932), on the basis of their experiments, concluded that royal jelly contains vitamin E. However, they did not use a standard method of procedure for vitamin E assay. Later Schoorl (1936), Mason & Melampy (1936), Evans *et al.* (1937), and Haydak & Palmer (1938) obtained no evidence of the presence of vitamin E in royal jelly. These experiments constituted the beginning of a series of investigations on the vitamin content of royal jelly. Melampy & Jones (1939), using biological assays, found that the vitamin B_1 concentration of fresh royal jelly was 1.0 to 1.5 I. U. per gram. No demonstrable amount of vitamin A was found and little, if any, of vitamin C was present. Haydak & Palmer (1940), on the basis of bioassays, concluded that royal jelly exhibits vitamin B_1 activity toward polyneuritic rats equal to about 3 micrograms of thiamine chloride per gram of fresh and 9 micrograms per gram of dry matter. In a later study (1942) the same authors, using laboratory rats, found royal jelly to contain about 50 milligrams of pyridoxine per gram of fresh matter. Microbiological

and microchemical investigations showed fresh royal jelly to contain from 1.5 to 3.0 micrograms of thiamine, about 9.5 micrograms of riboflavin, 80 to 100 micrograms of nicotinic acid, 0.68 to 0.75 micrograms of pantothenic acid per gram. The latter numbers did not agree with the values obtained by Pearson & Burgin (1941) who found royal jelly to contain 183 micrograms and 511 micrograms of pantothenic acid per gram of fresh and dry matter respectively. They considered on a mass feeding basis, the worker larvae are undernourished. "The queen and worker larvae have the same approximate growth rate during early larval life and then the growth of the worker caste is retarded, as shown by the nitrogen, total lipids, total reducing substances and calorific value" (Melampy *et al.*, 1940). This is shown by the different growth curves of the worker and queen larvae, the final weight of the former being around 162 milligrams (Nelson & Sturtevant, 1924)

Table 4.—"B" vitamin content of royal jelly (micrograms per gram) (Cheldelin & Williams).[1]

Royal Jelly	Thiamine Chloride	Ribo-flavin	Pyri-doxine	Nico-tinic Acid	Panto-thenic Acid	Biotin	Inositol	Folic Acid
Fresh	6.6	8.2	2.4	59	89	1.7	100	0.20
Dry	21.0	26.0	7.7	190	290	5.4	310	0.62
Max.–Min.	7.4–5.6	10.0–6.6	2.5–2.2	47–73	110–65	1.8–1.6	150–78	0.22–0.16

[1] Haydak, Palmer and Vivino (unpublished results) by chick assay did not find vitamin K activity in fresh royal jelly.

that the presence of pantothenic acid in such relatively large amounts does suggest that it might be one of the factors responsible for the development into queens of the female larvae which continue to receive royal jelly. Cheldelin & Williams (1942) investigated the "B" vitamin content of royal jelly. Their results are presented in table 4.

A number of investigators have attempted to explain the development of castes in the honeybee colony.

Klein (cited by Becker 1925) considered that the development of the female honeybee larvae into the worker or into the queen is conditioned by the type of feeding which they receive through a relatively long period of time.

The writer is of the opinion that the production of either a worker or a queen is due not to the change of food but to the amount of essential nutrients consumed by the queen and worker larvae. Up to about the third day of age, all female bee larvae are in the period of mass feeding (Lineburg 1924). After that time the larvae in the worker cells are fed progressively, the food being given to them in the intervals as needed. According to J. I. Hambleton (personal communication) the progressive type of feeding of worker larvae is a necessity due to the small size of the worker cells.

While the queen larvae continue to be while that of the latter may be over 300 milligrams (288, 300, 301 mg., writer's weighings). This is a typical case of partial inanition. Besides that, one has to take into account the fact that the worker larva after sealing has to spend a certain amount of materials of its own body for the secretion used in production of a cocoon, while queen larvae are sealed with an abundance of food present in the cell, and so can restore materials used in cocoon spinning by ingestion of more food.

The starvation of the worker larvae after sealing is shown in the decrease in weight by the end of the cocoon spinning activity. Shortly after sealing the average weight of a worker larva, according to Nelson & Sturtevant (1924), is about 162 mg. while a day later it is already 148 mg., and 141 mg. the following day. The queen larvae actually grow after sealing. The larvae in sealed cells in which cocoons were not yet started, weighed, according to the writer's determinations, on an average 192 mg. (8 weighings); those which barely started the spinning of the cocoon weighed 213 mg. (25 weighings) and those which had their cocoons made or almost made, on an average, weighed 278 mg. (11 weighings). So in the case of queen larvae there is no underfeeding at any time of the larval life, while in the case of worker larvae a partial inanition starts

after the larva attains the age of about 2.5 days. According to the metabolic studies of Melampy & Willis (1939) "It is evident that differentiations between the two castes is well under way by the second day of larval life. The pronounced physiological effect of the change in the diet of the workers is clearly demonstrated. The queen pupated at an O_2 consumption of 355 cu. mm. per insect per hour, the worker transformed at an O_2 consumption of 50 cu. mm. per insect per hour. The queen weighed, on an average, 256 mg, at the time of pupation and the worker 134 mg." However, it is probable that this difference in the metabolic activity is rather due to the fact that the worker larvae pupate in a state of starvation, while the queen larvae have food always available.

There are also cytological differences in the development of the queen and worker larvae, which "become evident during the third day of larval life when nuclear fragmentation (amitosis) occurs in some fat cells of queen larvae. Fragmentation begins a day later in the worker fat cells. Formation of albuminoid granules within the fat cells occurs near the end of the fourth day of larval development in the queen but during the sixth day in the worker" (Mickey & Melampy 1941).

Rhein (1933) reared honeybee larvae artificially in a constant temperature chamber. He had many setbacks when he tried to rear them from the egg stage, so, in the later experiments, he used two to four days old larvae. He fed them with "royal jelly" obtained from queen cells, with "larval food" taken from the worker cells, containing larvae under 18 mg. (under 2.5 days of age), and with "Mischfutter" the food from the worker cells with over 53 mg. heavy larvae (over 3.5 days old). He was not successful in rearing worker larvae on the "larval food," only 5 out of 24 reaching the weight of normal worker larvae, but even they failed to pupate. He was able to rear two to three days old worker larvae on royal jelly but he obtained only worker pupae (9 out of 28). The time of pupal development was equal to that of the worker.

The fact that he was unable to rear worker larvae on "larval food" led him to conclude that "royal jelly" and "larval food" are not identical in their composition. When Rhein fed queen larvae of various ages with "Mischfutter" he found that from under 20 mg. heavy larvae he received typical workers. In pupae development from 21 to 46 mg. heavy queen larvae fed with "Mischfutter" there were already changes to the queen type: ovarioles count was over 100, some had developed spermathecas and reduced pharyngeal glands. In pupae obtained from 48 to 146 mg. heavy queen larvae internal organs were of the queen type and the mandibles were toothed also.

His failure to rear queens from smaller queen larvae, Rhein explained by an assumption that a special determining factor of a hormone-like character (Determinationssekret) was missing in the "royal jelly" which he fed to those larvae. Only those pupae which showed a greater number of ovarioles and developed spermathecas seemed to have received some of this secretion in their early development as larvae. Rhein thought that either the substance is highly perishable or that it is fed to the queen larvae directly. He has not seen a single case of a direct feeding, but he observed that the nurses deposit alternatively the milkish and the clear-yellowish substance in the cells, so that a freshly secreted "royal jelly" had an appearance of a stratified deposit.

Rhein supplied over-3-days-old worker larvae (41 to 152 mg.) with an abundance of the "Mischfutter" and obtained large adults which showed both internal and external characteristics typical to workers. A 33 mg. queen larva and 45 mg. worker larva fed with the "Mischfutter" developed into pupae with the external characteristics of workers. The pupa reared from the worker larva was larger but had 6 and 14 ovarioles while that reared from the queen larva was smaller but had 124 and 150 ovarioles for the left and right ovary respectively.

Rhein came to the conclusion that queen larvae receive a different kind of food at the beginning of the differentiation than later in the development. This differentiation begins, according to Rhein, in queen larvae as soon as they pass the weight of 20 mg. So it occurs sooner than the differentiation in worker larvae which happens when the larvae attain the weight of about 35 mg. The differentiation is almost complete when the queen larva attains the weight of 150 mg.—about two-thirds of its final weight.

The writer decided to obtain adults from growing queen larvae by depriving them of food. In this case the larvae either die, or pupate and change to adults, depending on the physiological condition at the beginning of starvation. It was assumed that if a determining factor of Rhein is added to the food of the young queen larvae, then from the older queen larvae only queens would be produced, in spite of the starvation. However, if the undernutrition plays a role in the determination of the resulting adults, then worker bees or creatures closely resembling them would be obtained.

A number of weighed larvae, taken from sealed cells, were placed without food in a constant temperature chamber with the temperature adjusted to 33° C and relative humidity of 75 per cent. Velich's (1930) technic was applied. The larvae were watched individually. The shape of the head, mandibles, the sting and the presence of pollen baskets was noted in adults or in papae when the insects died in the late pupal stage.

Only one live adult, resembling a worker, was obtained, having a typical worker's head, mandibles and a straight sting. The head and mandibles were smaller than those of a normal worker. Seven pupae, dead in the late stadium of development showed the head, mandibles and the sting of the worker's shape. The pollen baskets in all cases were either absent or poorly developed. Eight larvae developed into normal queens. There were also transitional types of pupae present. None of them developed into an adult. The average weight of larvae from which the worker-like insects were produced was 204 mg. Those developed into queens weighed, on an average, 232 mg.

In order to understand how varying degrees of nourishment affect the development of larvae we have to study the structural changes which occur during the larval life of bees.

Zander *et al.* (1916) made histological studies of the development of the sexual organs of the worker and queen of the honeybee. The reproductive system of the female honeybee larva consists of two ovaries which, as two small solid cell plates, are located under the dorsal wall of the 8th segment, between the mid-intestine and the heart. A large number of lump-like processes are present in the dorsal wall of the plates. These processes are rudimentary ovarioles.

During the larval stadium of the queen the peculiarities of the inner structure remain almost unchanged. Only the number and the size of the rudimentary ovarioles is increased. The external form of the ovaries in comparison changes little. Only a swelling of the ends occurs which is caused by the development of the distal ovarioles (Endovarioles). Also the position of the ovaries in the body doesn't undergo any shifting. At the end of the larval period they are still located under the 8th segment. With the beginning of the prepupal stadium (Nymphenzite) profound changes begin to occur in the ovaries. Their position is also changed. After the evacuation of feces on the first prepupal day the larval mid-intestine collapses, the ovaries take a deeper position in the body and loosen themselves almost entirely from the heart. Through such a displacement more room is acquired for the new important changes. First, a shortening and thickening of the ovaries occurs. This thickening of the ovaries is characteristic of the prepupal stadium and goes hand in hand with an increase in the length of the ovaries. In two days old prepupae the short swellings on the main body of the larval ovaries on which the ovarioles rest in groups, undergo a considerable extension and splitting into branches.

During metamorphosis this condition undergoes striking changes. Because with the formation of the intersegmental pockets the abdomen is shortened from the caudal end (rear), the ovaries move again and assume their final position in the 7th segment. At the same time the ovaries turn around the point of their attachment to the ovarial cords on almost ninety degrees ventrally, so that the hitherto dorsal surface is directed toward the thorax. In this way the ovarioles which were directed dorsally assume a position characteristic for the adult insect, namely parallel to the axis of the body. Beginning with the second day of the pupal stadium the growth in the oral direction begins. Because of the intensive growth of the ovarioles in the oral direction, on the second day of pupal stadium the ovaries enter the 6th segment.

The growth of the ovaries is only partially caused by the greater development

of the ovarioles. To a great degree it should be ascribed to a stronger proliferation of the hitherto scanty enveloping and interstitial tissues, which starts from the second day of the pupal stadium. The ovaries are enriched in fat and also numerous tracheae enter this organ. The ovarioles extend so much that already on the 3rd day of pupal stadium their anterior ends begin to form the U-shaped loops which are characteristic of the adult.

The changes which the primitive state undergoes in the worker during the larval stadium, follow at the beginning those described for the queen larva. Up to the second day the worker and the queen larvae have about the same number of ovarioles. In further development the number of the ovarioles increases in the worker, but not to the same extent as in the queen. Up to the second day, there is a similarity in the size of the ovaries of the queen and worker. Afterwards, the size of the ovaries of the worker larva remains far behind that of the queen, in spite of the increase in the number of ovarioles. At the end of the larval period, the ovaries reach about the size of those of a three-days-old queen larva.

The shape of the ovarioles changes little during the larval stadium, but after the second day the increase in their length does not progress at the same pace as the growth of the ovaries. This is due to a different relation between the enveloping tissues and the ovarioles. While in the queen the ovarioles penetrate the enveloping tissues up to the dorso-medial edge, in the worker such an ingrowth does not occur, but the ovarioles remain close to the place of their origin (Anhängeband) as club-shaped outgrowths. In spite of the basic similarity between the development of the queen and the worker, there is a critical period for the worker larva around the second day of its life.

During the prepupal and pupal stadium the ovaries undergo profound changes in form and structure. The relation between the ovarioles and the enveloping tissues existing at the end of the larval stadium tends to intensify at the beginning of the prepupal stadium. This results from the fact that the growth of the ovarioles is behind that of the ovaries: the former never penetrate the distal half of the ovaries. Due to this fact, a large wedge of the enveloping tissue is formed.

As in the queen, at the beginning of the prepupal stadium the button-like swellings on the larval ovaries start to grow, forming ovarioles. The number seems to be not substantially reduced (110 to 115 of them on the first prepupal day). Beginning the second prepupal day the ovarioles begin visibly to shrink. Only a variable small number thicken and change into club-shaped formations, attached to very slender stalks. Hand in hand with this goes a continuously increasing shortening of the lateral plates (Seitenplatte)—in the site of the origin of the ovarioles.

During metamorphosis the majority of the ovarioles disappear. The "Seitenplatte" contract more toward the ovarian cord and from the second day of pupal stadium form quite a wide lumen. Only a few club-like thickened ovarioles extend cephalad and grow through the enveloping tissues. Their formation proceeds in the same way as in the queen. They grow uninterruptedly up to the end of the pupal stadium and reach, as was established by comparative measurements, the same length as those of the queen.

Histological studies of Oertel (1930) showed also that in the worker "near the end of the larval period, the ovarian tissue, not including the remaining ovarian tubules, decreases in amount. During metamorphosis the size of the ovaries and the number of ovarian tubules are diminished, but a few tubules remain and complete their development."

These histological findings are supported by the practical and scientific attempts to rear queens from worker larvae. Klein (cited by Becker: Zander & Becker 1925) used worker larvae of different ages (half a day to six days) for queen rearing, placing them in queen cells, from which the queen larvae were removed, and letting the bees feed those added larvae. He obtained gradual transitional types from the worker to the queen, depending on what age of larvae he used. He also tried to rear in worker cells larvae taken from queen cells. He experienced some difficulties because older larvae could not be conveniently placed in worker cells or the worker removed them. He was successful with younger larvae, from which normal bees were produced. Later he tried again to work with the older queen larvae and in this case he succeeded in rearing two imagoes of which one was a pure

worker and the other, produced from a still older queen larva, which was sealed sooner than the first, resembled a worker more than a small queen, but had some characteristics of the queen too. Klein considered that the course of development of the female larvae either to the queen or the worker type is determined by the kind of nutrition of larvae and not by an addition of some mysterious substance to the food which suddenly awakens in the larvae a predisposition to become the queen or the worker.

Becker (Zander & Becker 1925) started queen rearing from half- to four-day-old larvae. He sectioned the resulting pupae and determined the differences in the structure and size of the mandibles and pharyngeal glands, ovaries, number of ovarioles and the size of spermatheca. He found that all the curves of development for different organs run, for a period of time, on the same height as for normally developing queens. Then all of them fall abruptly except the pharyngeal gland curve which stays almost at zero up to the third day. Between 3 and 3.5 days it begins to rise and then from 3.5 days on, rapidly reaches the worker's size. The curve of the number of ovarioles of the right ovary of queen pupae reared from up to 3.5 days old worker larvae stays around 150 ovarioles, while in those from older worker larvae sinks abruptly to the number of the worker's type. The size of the ovaries runs parallel to that of the number of ovarioles. Becker concluded that in the worker larvae, between 3 and 3.5 days of age, there is, inside of 12 hours, a striking change of the structural pattern (Organisationsbild) of the queen into that of the worker.

What is the cause of such a change, and how can the final development of the worker and the queen type of the female bees be explained? Let us examine the effect of undernutrition on a growing animal. According to Jackson (1934), "Inanition profoundly affects the reproductive tracts of both sexes." Due to these changes, "The endocrine function of the ovary is inhibited. In the young, inanition usually causes a variable degree of ovarian atrophy. Chronic underfeeding results in the retardation and repression of sexual development." Other internal organs are affected too. In rats maintained at the same weight between the age of 3 and 10 weeks the ovaries lost 27 per cent, the spleen 42 and the thymus 90 per cent of their original weight. Haydak (1935, 1936) has established the fact that a protein rich food of the nurse bees tends to increase the nitrogen content of the abdomens of bees reared by them. He did not investigate whether it was due to the greater stores of protein in the fat body or whether the ovaries of the emerging bees were also more developed. That the number of ovarioles in the workers varies greatly is a known fact. Kozhevnikov (1925) counted as low as 3 and as high as 38 ovarioles for both ovaries combined. The writer found a total as high as 59 ovarioles for the two ovaries of a worker.

That the effects of undernutrition are likely to be the same for insects is evidenced from the following statement by Jackson: "Although the phenomena of inanition vary very greatly among different species and individuals, there are, nevertheless, certain features of general agreement. The similarity of effects is to be expected, since the changes are due ultimately to interference with the cell metabolism; and this metabolism is essentially the same in all living organisms." That the ovaries of worker bee larvae are retarded in their development is proved by the work of Meyer, described previously. There is a change in the diet and in the type of feeding shortly before this retardation in the ovarian development occurs. We can assume that the delay in the development of ovaries is due to the restricted diet to which the older worker larvae are subjected in the later stadium of their growth. Hoffmann (1933) in his study of the influence of starvation on the growth and reproduction of Lepidoptera found that "in the adult females produced from caterpillars which were subjected to starvation in the later part of their development there was a smaller number of eggs in the ovaries (21 against 213 in normal) and there was a reduction in the size of the ovaries and the oviduct."

Salt (1927) gives evidence from his own observations and from the literature that stylopization causes underdevelopment of the ovaries of parasitized female bees. "In the insects with a fixed amount of food for larvae (*Andrena*) the effect of stylopization is more pronounced, because the larvae cannot increase its ration. In the bees whose larvae are fed during their

development by nurses, these effects are not so pronounced." In the former case there is a partial inanition which causes the same effects as in the vertebrates. Besides this internal change there is "alteration of the ordinary somatic and secondary sexual characters, the latter being or tending to be interchanges." These changes are more pronounced when stylopization starts in the earlier stages of life. Salt concluded that "The effect of stylopization seems to be capable of explanation on the basis of an upset in the nutritional balance of the host which affects the reaction of the sexual hormones and produces intersexes."

Ezhikov (quoted by Smirnov & Zhelochovtsev 1926) discovered that in flies undernutrition of larvae is accompanied by significant changes in the inner organization of the imagoes in which the number of the ovarioles decreases and the histological structure of the ovaries changes. Weidling (1928) found that complete starvation in the larval stadium of Diptera has a profound influence on the resulting adults; the starved individuals did not reach the size of the controls and the average number of ovarioles in the starved individuals was greatly diminished. Köhler (1940) also found that the reproductive ability is strongly dependent on nutrition. Females from the best fed stocks laid, on an average, 303 eggs, while those from the least fed only 93. The duration of development was also prolonged.

Although there seems to be ample evidence (cited by Salt 1927) that the development of the secondary sexual characteristics in insects is independent of the sexual glands, nevertheless, the appearance of male characteristics in females with under-developed ovaries is an interesting phenomenon worthy of further investigation. Two more recent works throw a new light on this subject. Christie (1929) made an infestation of grasshoppers by various numbers of eggs of a Mermis nematode parasite. He found that in every case where the number of parasites per grasshopper was one, two and three they were females; where from 3 to 23 a mixture of males and females often occurred, while in all cases of 24 and over the parasites were males. Thus the amount of available food per parasite influenced the sex ratio of the resulting parasites. Christie concluded that in this case "the environment is an important sex determining factor, a factor which becomes potent, not during the early ontogenic stages, but only after a well-developed, highly differentiated larvae has been formed." Rempel (1940) studying parasitism by nematode worms in females of Chironomidae found various degrees of sex reversal in the parasitized insects. The intersexes graduated from almost perfect females to individuals which, although the body structure were those of females, possessed a completely regenerated male reproductive system, and the degree of intersexuality was correlated with the time of the destruction of ovaries: the earlier they were destroyed the more profound changes toward maleness occurred. A typical intersex was a female with external and internal male reproductive structures. "Thus the external genitalia are distinctly under the control of the sex cells, this control, as in vertebrates being in all probability exercised through the medium of a hormone, for it has been shown that in Chironomus in genetically female individuals the typical genitalia develop only in the presence of ovaries."

In this case of the queen honeybee there is no intersexual change since both the worker and the queen belong to the same sex. Similar relationship exists in the ants in which the queens, soldiers and workers are of the female sex. Vendel (1930), studying the reproduction of intercastes in the ant *Pheidole palluda* due to the influence of parasitism, found that if the parasitism of the soldiers starts early in life then a creature of the worker type results, if later in life—the type closer to the soldier appears. He found also some intermediates between the soldier and the queen, which he explained by the "feminizing" action of the parasites. It seems to be more probable, however, that all the transitional types between the queen and the worker, observed by Vendel, are the results of the degree and the duration of the undernutrition caused by the parasites to which the female larvae were exposed during their development.

Goetsch (cited by Trager 1941) found that in the same species of ants "the type of food determined which caste developed. Larvae fed pieces of insects, meat or coagulated egg white developed into soldiers, while those fed sugar or honey developed into workers. Ant larvae given

fluid protein such as blood, meat juice or raw egg white developed into workers as on sugar solutions. Apparently a high concentrated protein diet is necessary for the development of soldiers. Under natural conditions only relatively few larvae would happen to find near them fragments of insects and meat. Consequently only a few soldiers are developed, whereas the majority of larvae get liquid food and become workers." Emery (cited by Wheeler 1937) also observed that the soldiers, male and presumably female larvae of *Pheidole pallidula* are more assiduously fed (in this case by regurgitation only) than the worker larvae. Wesson (1940) in his experimental study on the caste determination in ants added an equal number of *Leptothorax curvispinosus* larvae to *L. longispinosus* workers deprived of the queen and the brood. These workers served as nurses for the added larvae. Then one colony was given a superabundance of food, consisting of egg yolk, sugar syrup and grasshopper legs. Another colony was given the same kind of food but just enough to allow the larvae to grow. The results were significant: 94 per cent of larvae developed into queens in the first case and only 30 per cent in the colony on a restricted diet. Wesson concluded: "In all probability with the ant *L. curvispinosus* only one type of female eggs is laid and these eggs become queens or workers respectively according to the nature of at least one environmental factor acting upon them after being laid. The determination of queens and workers was affected at a comparatively advanced stage in larval growth, indicating that the final determination may be considerably postponed. Undernutrition prolonged the development of workers. Even though the undernourished colony was getting much less food, the queen larvae have matured at the same time as the larvae in the well-fed colony, while the maturation time for the rest of the brood lagged considerably behind that of the queen larvae. It appears that the female caste of *L. curvispinosus* is determined trophogenically and not blastogenically."

In the light of the presented findings and discussion it is possible to postulate why such differences appear in the characteristics of the queen and the worker. Goldschmidt (1931) expressed an opinion that hormones play a part in the determination of sexes in insects. When some pathological or nutritional conditions interfere to a certain degree with the normal development of hormone producing organs, then the changes which are influenced by this hormone are less pronounced. It has been pointed out previously that there are certain changes in the structure of ovaries as a result of inanition. Older worker larvae have much less developed ovaries than the queen larvae of the same age. Komarov (1935) presented evidence that in the transitional types of female honeybees the size and development of the ovaries corresponds to the modified type of structural characteristics of the transitional specimens. Gontarski (1941) described such transitional types found among the supersedure queens. He pointed out that such gradual changes from one type to another are possible because of the fact that the determination is not dependent on the age of the larva but is possible also in the later larval life. Salt (1931) stated that "the intersexual characters produced by stylopization do not appear at haphazard, but in a definite sequence"—depending on the degree of stylopization. The same phenomenon was found by Rhein (1933) in honeybees. He stated: "The differentiation (in queens) begins first in the ovaries, in spermathecas, and in pharyngeal glands and ends in mandibular glands which is the latest determined organ. So it appears that the organs are determined not simultaneously but one after another." From his tables it is evident that the external changes characterizing the queen are present only in those individuals which have their internal changes complete. Gontarski (1941), who considers the worker to be a prototype, described the loss of worker's characteristics in the transitional types in the sequence which reversely follows the same changes as found by Rhein.

The facts presented in this paper lead the writer to postulate that the anatomical and physiological differences between the worker and the queen honeybee are, to a great extent, due to the hormone or hormones which in the case of the highly nourished queen larvae are secreted by the fully developed ovaries in a sufficient quantity to cause those structural and physiological changes which characterize the queen. In the case of the worker

larvae, which have their ovaries in a rudimentary state, this phenomenon does not occur.

Whether the same hormone or hormones cause the suppression of the development of the pharyngeal glands or what is their interaction with the activity of other hormones playing a part in the determination of the queen honeybee cannot be answered now.

That there is such an interaction between various glands in insects is evident from the recent studies by several investigators. Weed-Pfeiffer (1939) found that a complete removal of *corpora allata* from adult females of the grasshopper prevents the production of ripe eggs and secretion in the oviduct, thus indicating that the *corpora allata* play an important part in the physiology of the reproductive system. In the discussion of the results, Weed-Pfeiffer stated: "Since the *corpora allata* are glandular organs located some distance from the ovaries and oviducts it seems probable that they exert their influence through the agency of a hormone transported by the blood. This is further suggested by the observation that the ovaries and oviducts respond to the presence of grafted *corpora allata*. It was also seen that if even a small fragment of *corpora allata* was left in the head, ripe eggs were produced and secretion appeared in the oviduct. However, the response of the ovaries and the oviduct was delayed. The fact that this delay was accompanied by hypertrophy of the fragment suggests not only that a hormone is involved but also that this hormone must reach a certain threshold level in the blood before it is available to stimulate the reproductive system." Vogt (1940) established that for the maturation of ova in the transplanted ovaries of *Drosophila melanogaster* into *D. funebris* the presence of the ring glands of the same species is necessary. The gonadotropic action of the ring glands begins in the later part of larval life, at least several hours before the puparium formation. Thomsen (1940) found that extirpation of the *corpora allata* in one day old flies of *Calliphora* and *Lucilia* resulted in the stopping of the development of the ovaries while the controls showed mature large ovaries. However, according to Pflugfelder (1937) the queen honeybee has *corpora allata* only slightly larger than the worker. Bodenstein (1943) proved that the ring gland in *Drosophila* is necessary for the growth and metamorphosis of the salivary glands. Pflugfelder (1939) transplanted *corpora allata* from younger nymphs (II–IV instars) of *Dixippus morosus* to the older nymphs (V–VI instars) and observed that this resulted in an exceptional enlargement of the pericardial and ventral glands in the giant animals. The extirpation of the *corpora allata* resulted in a premature degeneration of these glands, thus indicating a close coordination and a reciprocal action of these organs and the *corpora allata*. Thomsen (1940) found that in the flies (*Muscidae*) not only does the *corpus allatum* control the ripening of the ovaries in the normal adult, but also the growing ovaries influenced the size of the *corpus allatum* which in the absence of ovaries hypertrophy. Pfeiffer (1940) observed the same phenomenon in the grasshopper, *Melanoplus differentialis*. The observations of Salt (1931), Rhein (1933), and Gontarski (1941) on a certain sequence in which the internal changes appear in the female honeybee larvae suggest that such an interplay of hormones exists in the honeybee also.—5-29-43.

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The Pales Weevil in Southern Pines[1]

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The pales weevil, *Hylobius pales* Herbst, is generally recognized as an important pest of young pines, particularly eastern white pine, *Pinus strobus* L., in the northeastern states. Peirson (1921) worked out the life history, habits and control of this insect in New England and showed that its range extended beyond the limits of white pine, its preferred host. He also listed many other conifers as known food plants and suggested that still other trees were probably fed upon in areas where white pine did not occur. This assumption has since been proven correct.

Although the pales weevil has often been collected from the southeastern states, there are, as far as the writers are aware, no previous records of injury by it to any of the southern pines. It first attracted attention locally during the summer of 1940, by seriously damaging reproduction of loblolly pine, *Pinus taeda* L., and shortleaf pine, *P. echinata* Mill., in recently cutover areas on the Duke Forest. Subsequent studies have revealed that in the South this species differs in its life history and habits from those recorded in New England. In the vicinity of Durham, there is one complete generation and a partial second overlapping generation annually; it appears to breed only in the roots of stumps and dying pines; and the larvae feed singly. Otherwise, its habits are similar to those in the north as described by Peirson (1921).

SEASONAL HISTORY AND HABITS.—The adult weevils hibernate beneath the litter and emerge during the first warm days of spring about the middle of March, the time of emergence varying somewhat with weather conditions. This flight only slightly precedes the flowering of shadbush, *Amelanchier canadensis* L. (Med.), one of our earliest flowering shrubs. Beginning a month or six weeks later, there is also an emergence of adults from overwintered nearly full grown larvae, and again in the fall from eggs laid early in the summer. In fact, the weevils can be found in flight and doing some feeding during the entire summer but the heaviest damage occurs during June and July.

By late March or April the first emerging females usually seek suitable places in which to lay their eggs. They often burrow deep into the soil to oviposit in the bark of the roots of stumps and of dying pines; also around the root collar below the ground line. In addition, females oviposit in the inner bark of pine logs and larger pieces of slash, especially around the edges of fresh wounds such as axe cuts and bruises, but during this study no

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successful brood development was found in this class of material. Savely (1939) reported finding larvae in pine logs in this area and Peirson (1921) records them as breeding in pine logs in New England. In several attempts to verify this point no weevil larvae other than *Pissodes nemorensis* Germ., which were common, have been found in either stumps or logs.

The eggs are deposited singly in punctures on all sides of the roots, although somewhat more abundantly on the lower sides. The larvae make irregular tunnels and feed singly although if they are numerous enough, most of the phloem may be destroyed by the time they reach maturity. Overwintering larvae do not construct the chip cocoons until the following spring.

From the data available it appears that eggs laid by June or earlier produce adults which emerge during late summer or early fall, and that eggs laid later in the season produce adults which emerge the following summer but considerably later than the hibernating weevils.

The weevils are nocturnal, feeding principally at night and hiding in the litter or beneath chips, logs or other debris during the day. They are attracted by the odor of pitch and heavy concentrations frequently occur where pines have been disturbed.

NATURE OF INJURY.—The adults feed on the thin bark of the main stem and branches of pines of all sizes, eating it off in irregular patches and at times removing all of it on seedlings. Damage is proportional to the size of the trees, and the number of beetles present. Young pines from the seedling stage up to 4 or 5 feet in height are most seriously damaged, especially if in the vicinity of freshly cut stumps, dying pines and of logging or building operations. The fact that the pales weevil is attracted to the vicinity of pines infested by bark beetles, where they feed on the surrounding reproduction and the limbs of the infested trees, later breeding in the roots, has not previously been noted. Examination of two small "spot-kills" of shortleaf pine infested by the southern pine beetle, *Dendroctonus frontalis* Zimm., in western North Carolina during the summer of 1941 showed that much of the pine reproduction in the immediate vicinity of these trees had been killed by the pales weevil. Similar observations on both "group-kills" and single infested pines dying as a result of attack by engraver beetles, *Ips*, have shown that any reproduction within a relatively small radius of these trees is commonly attacked and killed by the pales weevil in a manner not unlike that in cutover areas. It is also interesting to note that while most of the feeding is in a zone from below the ground line to a height of 4 or 5 feet, adults have been found feeding on branches as high as 35 feet from the ground.

Counts on cutting plots sampled in 1940 revealed that about 30 per cent of all pine reproduction up to 5 feet in height was killed during a single summer attack by weevils which were attracted to the area by the presence of pine stumps left after logging the previous winter. Similar losses were encountered the following year when pines were cut near seedling stands. Subsequent studies have indicated that an unknown number of small dead seedlings were probably missed because they disappear so quickly after being killed by the weevils. No satisfactory method has been developed for measuring damage to young trees which were heavily fed upon and apparently dwarfed, but not immediately killed.

FOOD PLANTS.—Locally the weevils have been observed feeding upon the native loblolly and shortleaf pines, and upon planted Scotch pine, *Pinus sylvestris* L., longleaf pine, *P. palustris* Mill., and red pine, *P. resinosa* Ait. Apparently none of the pines is immune to attack. Planted Arizona cypress, *Cupressus arizonica* Greene also suffered severe damage and planted eastern redcedar, *Juniperus virginiana* L., was fed upon to some extent.

MEASURING THE DAMAGE.—Losses by this insect have been notably heavier in areas where the group selection method of harvesting was used than where clean cutting in strips was employed. The proximity of the stumps to the reproduction is apparently the chief factor determining the amount of loss. The following test was made to check on the supposition that the intensity of feeding of the pales weevil on pine reproduction varies inversely as the distance from the source of attraction increases. In this test data were collected on five small plots of unequal area. The timber was cut from these plots in 1937 and during the next two years the plots were seeded and a

Table 1.—Total and dead pine seedlings on quadrats sampled for pales weevil damage.[1]

Transect No.	Distance from Edge of Clearing in Feet				
	10	20	30	40	50
1	18 11	10 2	19 2	17 4	7 1
2			5 5	1 1	5 4
3		3 1	3 2	3 2	3 2
4	14 10	26 8	30 5	22 6	9 2
5		9 9	5 4	5 1	3 0
6			6 5	3 3	2 2
7		3 3	1 0	12 5	9 2
8		1 1	2 1	3 3	2 2
9	3 1	14 0	28 2	8 2	6 0
10	10 4	7 1	9 0	7 1	5 0
11	1 0	1 1	16 7	6 1	1 0
12		1 0			2 1
13			1 1	3 1	3 0
14	8 4	8 1	1 1	1 0	5 0
15	8 0	2 1	7 0	6 0	4 1

[1] The entire number of seedlings on a quadrat is in the upper left of the cell; the number of those killed by weevils is in the lower right.

stand of loblolly and shortleaf pine reproduction was established. In the winter of 1939 some additional pines were taken out around the edges of these cleared areas. The following spring and summer weevils were attracted to the stumps around the edge of the plots and fed heavily on the young pines, killing many of them.

The five plots in which the feeding occurred are each about one-quarter acre in area and are more or less circular in outline. The damage to pine reproduction is measured in the proportion of seedlings killed by the weevils.

Three randomly selected transects were run from the edge of the cleared area 50 feet toward the center of each plot. Each transect was subdivided into five 10-foot quadrats, and the damage was recorded according to individual quadrats. The record is presented in table 1. The entire number of pine seedlings on the quadrat is listed in the upper leftof each cell of the table, and the number of those killed by the weevil is given in the lower right.

Regression analysis demonstrated that the average number, Y, of killed pine seedlings varies directly with the number, n, of available seedlings, and inversely with the distance, d, from the edge of clearing such that

$$Y = n\left(\frac{5.30}{d} - 0.012\right)$$

in which d is measured in feet. The standard error of the coefficient 5.30 is 0.079. Thus with $n = 100$, the calculated percentage of killed seedlings at distances 10, 20, 30, 40 and 50 feet are, respectively, 52, 25, 17, 12 and 9. This represents the seedling loss only during the first year after cutting. With the knowledge that additional losses may occur during the second year; that many of the smaller dead seedlings are missed in the survival counts; and that many of the living trees are seriously injured, it is apparent that damage by the pales weevil is likely to be much greater than indicated here. Where this insect is abundant it should receive consideration in the methods used for the establishment of pine reproduction in the south. Because of its feeding and migrating habits it is of greatest importance in areas where pine follows pine.—5-12-43.

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SCIENTIFIC NOTES

Derris Used for the Control of Head Lice and Pubic Lice

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Derris is an effective material for combating the head louse, *Pediculus humanus humanus* L., and the pubic louse, *Phthirus pubis* (L.). The application of derris powder to louse-infested heads is a practical method of controlling head lice, and if persistently and generally applied should result in eradication from a community, or, for that matter, from the world. Although effective against pubic lice, the advisability of a general recommendation for the use of derris against that species is questionable because of the irritation produced in a considerable percentage of individuals, especially when the material is used too freely.

During a period of several years, small quantities of derris powder were given for testing to individuals seeking advice on louse control. They were instructed to apply the powder sparingly but thoroughly to the affected parts and to leave it on at least overnight, the treatment to be repeated two or three times at intervals of 5 or 6 days. In some 50 or more cases, involving approximately equal numbers of infestations of head and of pubic lice, only favorable reports were returned. In a single instance a man reported that rather severe irritation in the pubic region followed the treatment. This soon cleared up although desquamation of the epidermis was pronounced. These early investigations were made under the direction of F. C. Bishopp, at that time in charge of the Division of Insects Affecting Man and Animals, Bureau of Entomology and Plant Quarantine, United States Department of Agriculture. These preliminary results were so encouraging that Dr. Bishopp made an effort to widen the scope of the investigations and to test the treatment in numerous cases which could be more closely observed.

In 1937 contact was made with Dr. Joseph A. Murphy, Director, School Medical Inspection Service, District of Columbia Health Department, who instructed school nurses to report pupils excluded from classes because of pediculosis. The occurrence of either the active stages or the eggs ("nits") on a child's head was considered pediculosis and resulted in his exclusion from school until the condition was cleared up. According to Dr. Murphy, 20 per cent of the enrollment in certain schools had been absent at one and the same time for this reason. Children sent home were disinfested there by various methods only to become reinfested in a few days by contact with other children or members of their own families.

The usual delousing methods do not destroy or remove eggs, and they do not prevent subsequent infestations. Derris powder, on the other hand, although not destroying or removing eggs, remains on the hair long enough, under the best conditions, to kill all young as they emerge and, while there, prevents infestations from other sources. To accomplish eradication of lice among a large group of people who continue their usual modes of life, it is usually necessary to make three applications of the powder at weekly intervals.

Consequently, in 1937 the late J. L. Webb, of the Division of Insects Affecting Man and Animals, and the writer visited a number of the homes of infested children, and tests of derris in powder form and as a shampoo were initiated. Both forms were found to be effective, but the powder was the more convenient to apply except in cases where characteristic crusts indicated the desirability of using the derris shampoo.

Finely ground derris containing about 3 per cent of rotenone was applied by means of an ordinary salt shaker and worked into the hair of the entire head, care being taken not to get the powder in the eyes. About 1 teaspoonful was used on each head. The parents were asked not to wash the powder out for 10 days or more, and to use a comb rather than a brush while the powder was present. A small supply of the material was usually left at the home for treatment of any other members of the family who might be infested. Hats were treated with derris, and instructions were left as to their care.

The shampoo employed consisted of 5 level tablespoonfuls of derris, 2 level tablespoonfuls of neutral soap, and 1 quart of warm water. This was applied thoroughly, and the surplus water was then removed with a towel without rubbing the hair dry. It was recommended that the head be not washed for 2 weeks so that the young emerging lice would be killed as the eggs hatched.

In addition to the city cases, records were made of several successful treatments at a country school in Montgomery County, Md.

This work was continued until 1940 and served as a basis for recommendations, in January 1942, to school authorities who were about to establish a louse clinic for school children and their families. The writer supervised the initial applications, and specific instructions were prepared for the guidance of the W.P.A. workers assigned to the project under the supervision of Miss Mildred Negus, Supervisor, Southwest (Washington) Health Center, and under the general direction of Dr. Joseph A. Murphy. This clinic was opened on February 4, 1942, and is being continued with marked success.

In view of the effectiveness of the treatment, school authorities permitted children to return to school as soon as the powder was applied, even though nits were present. The powder was not sufficiently in evidence in the hair to be objectionable. It was made available in blonde and brunette shades, although generally the tinted powders were not used.

In a paper read before the Southern Medical Association in November 1942 Dr. Murphy outlined the work of the clinic and said: "During the 5 months from February to June inclusive, 3056 treatments were given to 804 patients, of whom 406 were pupils, 248 were home contacts, and 150 reopened cases." One of Dr. Murphy's concluding statements was as follows: "Absence from school on account of pediculosis can be reduced from weeks or months to a few hours if pupils and home contacts are simultaneously treated and pupils be allowed to attend school during the treatment period."—9-13-43.

[1] Investigations carried on while the author was on the staff of the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

Certain Organic Bromides as Grain Fumigants

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Allyl bromide, ethylene bromide, and *n*-butyl bromide were tested as fumigants in 1929 by Roark & Cotton (1930). Under the conditions of the tests used—24-hour exposure, 200 gms. of wheat in a 500-cc. erlenmeyer flask, and dosages measured to 0.01 ml.—they found that the following minimum concentrations were lethal for the rice weevil: Allyl bromide, 28 mg. per liter (least dosage used); ethylene bromide, 87 mg. per liter; and *n*-butyl bromide, 102 mg. per liter.

Table 1.—The fumigating effect of some compounds containing bromine.

Compound	Molecular Weight	Boiling Point at 760 Mm., °C.	Sp. Gr. 20°/4° C.	Rice Weevil, Minimum Lethal Dosage Mg. per Liter			Confused Flour Beetle, Minimum Lethal Dosage Mg. per Liter		
				1 Hr.	24 Hrs.	24 Hrs. in Wheat	1 Hr.	24 Hrs.	24 Hrs. in Wheat
Allyl bromide $CH_2{:}CHCH_2Br$	120.96	71.3	1.398	17	1	6	23	3	10
Ethylene bromide CH_2BrCH_2Br	187.86	131.7	2.182	76	2	109	65	3	141
N-butyl bromide $CH_3CH_2CH_2CH_2Br$	136.99	101.6	1.275	382	22	89	318	32	102

Table 2.—The effect of some mixtures containing bromine.

Compound	Composition of Mixture, Per Cent by Volume	Sp. Gr. 20°/4° C.	Rice Weevil, Minimum Lethal Dosage, Mg. per Liter			Confused Flour Beetle, Minimum Lethal Dosage, Mg. per Liter		
			1 Hr.	24 Hrs.	24 Hrs. in Wheat	1 Hr.	24 Hrs.	24 Hrs. in Wheat
Fumigant A	Ethylene dichloride 67.5 carbon tetrachloride 22.5, methyl bromide 10	1.390	139	14	42	152	21	69
Fumigant B	Propylene dichloride 67.5, carbon tetrachloride, 22.5, methyl bromide 10	1.314	169	23	65	197	33	65
Fumigant C	Propylene dichloride 90, methyl bromide 10	1.216	144	12	48	168	30	72

In the literature that has been consulted no record has been found of further work with these compounds as fumigants. Therefore the writers have recently studied them again, using a somewhat different technique. The insects, both the rice weevil, *Sitophilus oryza* (L.), and the confused flour beetle, *Tribolium confusum* Duv., were fumigated in empty 20-liter bottles for 1 and 24 hours, or in 20-liter bottles filled with wheat for 24 hours. Where it was necessary to measure small dosages, pipettes graduated to 0.001 ml. were used.

The results obtained are shown in table 1.

These tests show allyl bromide to have excellent insecticidal properties. Its greatest weakness is its inflammability, but this can be counteracted by mixing it with carbon tetrachloride. Large-scale field tests were made with a dosage of approximately 2 pounds of allyl bromide made up to 2 gallons with carbon tetrachloride, the mixture being sprayed on the surface of 1000 bushels of wheat in steel bins. Test insects planted at various levels in the grain showed a complete mortality after 72 hours of exposure. A persistent odor in the fumigated grain may prove to be objectionable.

Germination tests were made and no loss of germination was found.

Tests of Mixtures Containing Methyl Bromide.—The satisfactory results obtained with methyl bromide as a fumigant in many fields led to many efforts to use this fumigant for treating grain stored in terminal elevators and farm bins. No success was obtained, regardless of the method of application, until the junior writer in 1939 suggested mixing methyl bromide with various diluents to overcome its high volatility. The 3-to-1 by volume mixture of ethylene dichloride and carbon tetrachloride was first used as a diluent, and a mixture containing 10 per cent of methyl bromide by volume was finally adopted by the manufacturers[1] as being most satisfactory from all standpoints. At a standard dosage of 2 gallons of the mixture per 1000 bushels of grain, this mixture is now being used rather widely commercially for the fumigation of stored grain.

Owing to the demand for large quantities of both ethylene dichloride and carbon tetrachloride for other industries during war time, the possibility of using other diluents was considered. The insecticidal properties of two such mixtures, prepared and supplied by the manufacturers, have been compared under laboratory conditions with those of the standard mixture of ethylene dichloride, carbon tetrachloride, and methyl bromide. The results given in table 2 indicate that the insecticidal values of such mixtures for the treatment of grain vary but little, regardless of the diluent used.—8-16-43.

[1] Dow Chemical Co., Midland, Mich.

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Anurida maritima: An Important Sea-Shore Scavenger

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Between the tidelines there accumulate great quantities of dead animal bodies. It is commonly known that gulls, crows, crabs, and some of the snails devour much of this debris, but very seldom is mention made of the Collembolan insects although their scavenging activities on land are well known. While studying marine life at Gloucester on Cape Ann, Massachusetts, the writer made many observations on the habits of *Anurida maritima* over a period of several years. This species lives on the tidal zone in very large numbers and plays an important part in keeping the strand clean of dead animal material. They literally swarm everywhere—over rocks, mud, and sand. Greatest abundance is found on and under rocks and over hard mud-banks and marsh-banks. Often they are so crowded as to form a solid mass of well over 100 per square inch. Great quantities of cast skins as well as the living specimens, which are bright metallic blue in color, are found under loose, flat rocks. Over the exposed shore these ubiquitous insects are found running rapidly in all directions, many following down the tide. They do not have a ventral spring characteristic of most of the Collembola, and consequently cannot jump. Carcasses of fishes, crabs, snails, etc. are soon found and become coated with these scavengers. If barnacles are crushed they soon become buried with *Anurida maritima* which clean out the soft tissues. As the tide returns this insect is forced back upshore. Many seek refuge in air bubbles trapped under rocks, in mud-banks and in gravel. Those not doing so are often floated upon the surface and are generally washed into tidal pools where they are found in large numbers until the tide retreats. Their waxy cuticle readily sheds the water. From extended observations over several miles of shoreline along a tidal inlet it would appear that this insect is fully as important as a scavenger as any of the larger animals, especially in the protected inlets and bays.—7-15-43.

DN Sulfur Dust Appears Effective Against the Sweetclover Weevil

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Work on the insecticidal control of the sweetclover weevil, *Sitona cylindricollis* (Fahr.), in the spring of 1943, although chiefly exploratory, furnished some results that appear worth publishing at this time.

Thus far most of the injury to sweetclover, *Melilotus* spp., by the sweetclover weevil in Wisconsin has been done by the adult beetles. They attack the new growth of second-year plants as soon as it appears in the spring, considerably retarding it, and the new seedings that come later may be completely destroyed. Emergency control through cultural practices is therefore out of the question, unless the plowing up of the sweetclover can be called a control measure, and the use on the new growth or young plants of some insecticide that will kill the weevils without injuring the sweetclover seems imperative. This spring (1943) the weevils attacked the new shoots while these were so small as to be found with difficulty. Thus it may develop that the best control may be obtained by applying the dust to the ground when only a few shoots, upon which the weevils are concentrating their attack, are present.

Insecticidal tests were made in the trial nurseries of sweetclover in the care of W. K. Smith of the United States Department of Agriculture and the Wisconsin Agricultural Experiment Station at Madison. The nurseries contained year-old plants in rows where they either had been grown from seed or had been transplanted. Three rows were used in most of the dusted plots and two or more rows in most of the checks. The plants when dusted ranged from 2 to 6 inches in height but most of them were under 4 inches.

When control measures became necessary these plants were too short to be swept with an insect net, so initial populations could not be thus obtained. It appeared impractical to cage dusted plants, since the soil contained many deep crevices into which sick weevils, some of which might die, could easily escape. It was thought that perhaps some indication of the effect of the various dusts could be obtained by observing the relative amount of feeding in the plots, but since only one of the dusts was very effective and the weevils are active crawlers, this method was impracticable. The method finally adopted was for two workers to collect weevils from the ground in each plot for a definite length of time and to use the number of living and dead weevils found as an index of effectiveness. This method is, of course, inexact, but it was the best that could be devised under the circumstances, in which speed was necessary, and the work was interrupted by much windy and rainy weather.

Dusts were applied with a knapsack rotary hand duster. In most cases the delivery was set at 10 pounds per acre, but the flow of the dusts was variable and some adjustments were made in an effort to obtain uniform deposits. The insecticides used were calcium arsenate, cryolite, rotenone, nicotine, DN sulfur dust (0.8 per cent dinitro-ortho-cyclohexylphenol), pyrethrum,and barium fluosilicate in various combinations with talc, micronized sulfur, magnesium oxide, and pyrophyllite.

DN sulfur was the only one of these dusts that showed good kill. In a plot that had been dusted under best conditions, and from which the writers were able to make collections within 20 hours after dusting with no rain intervening, counts showed a kill of 96.6 per cent. Many dead beetles covered with dust were found strewn about on the surface of the soil, thus indicating quick action of the chemical. The dead in other plots were usually found concealed around the plants or under clods. None of the plants was injured by the DN dust in these experiments.[2]

Of the other dusts, undiluted calcium arsenate appeared best, the kill being about 50 per cent. Barium fluosilicate showed some control. Rotenone 0.75 per cent in talc, rotenone 0.75 per cent and nicotine 2 per cent in pyrophyllite, rotenone 0.75 per cent in sulfur, and pyrethrum (0.2 per cent pyrethrins in talc) appeared worthless.—7-30-43.

[1] The authors appreciate the assistance of Lee Seaton in the field work.

[2] Slight to moderate injury by DN dusts has been observed in sweetclover since this paper was written. It occurred chiefly when the dusts were applied later in the season and both humidity and temperatures were high but it is not known whether or not these conditions were responsible for the injury.

Arsenate of Iron

HOWARD W. AMBRUSTER, *Westfield, New Jersey*

Arsenate of iron, an arsenical insecticide with a somewhat long and contradictory history, is of some possible interest in the present war emergency of a potential shortage of by-product arsenic.

Imports of arsenic from Japan and Sweden having been cut off, the deficiency has barely been made up by some increase in the production of the by-product by United States, Mexican and South American Smelters. However, the shortage for insecticide requirements may become a reality should the war be unduly prolonged and heavy infestations of bollweevil, army worm and codling moth occur, or should the threatened use of war gas in Europe or the far east require allocation to the Chemical Warfare Service of any large portion of the available by-product arsenic for use as arsine in Lewisite and other war gases.

To avert this threatened shortage of arsenic the utilization of large deposits of scorodite, a ferric arsenate of iron, at Gold Hill, Utah, has been considered by some of the government agencies responsible, this being the only large and partially developed supply of crude arsenic which appears available on the continent. The limitations of the by-product supply are of course apparent and have no relation to the current demand.

It was first proposed to extract the arsenic content of the Gold Hill scorodite ore as white arsenic, or arsenic trioxide, and to utilize this for either insecticide manufacture or for war gas as might be required. This procedure would reduce the arsenic content of the ore from the pentoxide As_2O_5 to the trioxide As_2O_3 which must thereupon be first converted to arsenic acid, H_3AsO_4, and then compounded with lead or calcium as an arsenate in which its value is, as in its original form, the pentoxide.

As a possible alternative to this utilization of the scorodite supply the author has suggested the use of the Gold Hill ore as natural insecticide.[1] I have accordingly assigned to the Secretary of Agriculture my U. S. Patent, 1,691,454, which covers the manufacture of an arsenate of iron insecticide by fine grinding and treatment of scorodite ore.

The Bureau of Entomology and Plant Quarantine has arranged to conduct a series of tests on scorodite arsenate of iron. At the direction of Dr. Ruric C. Roark in charge of Insecticide Investigations at the Beltsville laboratory, the American Smelting and Refining Co., which controls the larger of the Gold Hill scorodite deposits, has shipped a supply of the ore to the Micronizing Processing Co., Inc., at Moorestown, N. J. to be micronized by that company. It had been hoped that a supply of the fine powder might be available for some field tests to be made this season but this is hardly possible as this is written unless there should be a very late infestation of army worms in the delta cotton states.

The interest of some of the insecticide manufacturers has also been aroused and cage tests will undoubtedly be conducted by them during the winter to supplement work done by official agencies which may justify commercial production and field use at the start of next season.

Commercially arsenate of iron has been an accepted insecticide in Europe for many years. Compagnie Miniere & Metallurgique d'Auzon, one of the largest French arsenic producers and manufacturers, had it listed at about the same price as arsenate of lead in 1922.

The germ of the idea of utilizing scorodite ore for this purpose originated from that announcement.

In the United States there has never been any commercial production of arsenate of iron although one insecticide manufacturer did send out experimental lots as far back as 1910, when the arsenates were first replacing paris green and *London Purple*. Again in the late '20's it was supplied in the United States in small quantities for testing purpose when the spray residue problem first became acute and it was thought that if the lead was done away with or replaced by a less objectional metal the arsenic might be washed off, or ingested, with less uproar and inconvenience by all concerned.

In Canada, Deloro Smelting and Reduction Co. reported a production of 75,000 pounds of arsenate of iron in 1922 and Ontario Smelters and Refiners, Ltd., also sold a similar product during that period.

Both of these Canadian arsenate of iron insecticides were by-products of nonferrous smelting processes. They disappeared from the market when the by-product was no longer available.

The history of arsenate of iron as an insecticide is based chiefly upon a manufactured ferrous arsenate of iron $Fe_3(AsO_4)_2 \cdot 6H_2O$, whereas the natural product, scorodite, is the ferric arsenate iron, $FeAsO_4 \cdot 2H_2O$. The oxidation, in the latter, has taken place over countless ages and the ore of course is not a pure compound of iron and arsenic. A typical assay of the Gold Hill ore showed the following: silver, 3 per cent; lead, 2 per cent; zinc 1 per cent; sulphur 2 per cent; Iron 24 per cent; Arsenic, 20 per cent; and insolubles 14 per cent. These other non-ferrous metals should not detract from the insecticidal value of the product but increase it if anything. The ore supplied for the government tests is reported as averaging 19 per cent As, or approx. 28 per cent As_2O_5, which should be sufficiently high to demonstrate its toxic quality. However samples from the 800 foot level of the Gold Hill mine which I secured personally some years ago tested 27 per cent As, or over 40 per cent As_2O_5, and the quantity of the ore in the developed levels of the mine is so great that there should be no difficulty in taking from it ore of a high average arsenic content.

One somewhat strange feature of the scorodite arsenate or iron is its extremely low water soluble arsenic content. This may be due to a gradual leaching which was taking place while the oxidation of the ore body from an arsenite to an arsenate has slowly progressed. Whatever the method, nature has tied in the arsenic so tightly that only a trace of water soluble As_2O_5 is to be found in the ore. This is of course a decided advantage with respect to foliage injury but it also may be that the arsenic is so firmly bound that it will unduly resist dilution in the stomach juices of some insects, regardless of whether they are acid or alkaline in character.

Contradictions in the insecticide history of arsenate of iron date back to its first recorded use, in New Jersey, in the year 1907, when it was described as being "satisfactorily as effective as lead arsenate" against the army worm;[2] and, in France in 1913, "very feeble immediate insecticide action."[3]

[1] Arsenic, Encycl. Americana, 1943 Annual, p. 74: 1, Ambruster.

[2] J. B. Smith—Annual Report N. J. Agricultural Station, 1907.

[3] L. Moreau & E. Vinet—Paris, France, 1913.

It has also been claimed by one manufacturer that iron arsenate is more palatable to insects then other arsenicals (and therefore more effective), and by another insecticide maker who tested it, in England, that it appeared repellent or distasteful to caterpillars. Strangely enough in the first two contradictions the product was undoubtedly the manufactured ferrous arsenate of iron; the third was a smelter by-product, probably ferric arsenate; while the last was made from scorodite.

One of the most definite statements which appears relating to the insecticidal value of the product is found in U. S. patent 1,376,153, Moore,[4] to the effect that a ferric arsenate of iron, made by adding sodium arsenate to ferric chloride, was "more toxic than lead arsenate and shows a greater adherence to the plant." As it may be recalled Dr. Moore worked out the theory that a positive electrical charge will cause an insecticide to adhere better to plant life and apparently he secured his best results in those experiments with an arsenate or arsenite of iron.

Numerous reports of actual tests, rather than ex-parte statements or conclusions, appear to indicate that arsenate of iron has been found to have proven insecticidal value under various conditions.

Regardless of such historical contradictions as appear the toxic qualities of the scorodite arsenate of iron were sufficiently demonstrated in actual tests made privately some years ago although the fine grinding problem was not at that time considered to have been solved. This reduction of the particle size to its lowest ultimate dimension appears to be necessary and to offer the most promise for the successful utilization of scorodite as an insecticide. Admixture with other insecticide materials or with an ingredient which will in effect unlock the toxicity of the arsenic in the intestines of the insect without prior injury to the foliage may also help to solve the problem.

It may not turn out to be a commercially valuable or peace time competitive product but in the war emergency scorodite might serve a useful purpose to piece out a short supply of by-product arsenic by mixing this insecticide with calcium or lead arsenate for the cotton insects or codling moth.

When the arsenic shortage appeared in the offing it seemed best to turn the project over to the government in order that no commercial considerations, in so far as the private ownership of the patent was concerned, could hold back its possible availability. It is as a war emergency that scorodite may now be given attention by state experiment stations which considered it of no particular interest when it was first proposed as a possible commercial competitor of lead and calcium arsenate.—8-20-43.

[4] U. S. Patent on Insecticide, April 22, 1921, William Moore, St. Paul, Minn.

Frianite, an Insecticide Diluent

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Pumice, pumicite or volcanic ash, is recognized for its value as an inert carrier of liquid insecticides and a diluent of powders. This material is found in regions of past volcanic activity, frequently in deposits several feet in thickness. When mined it breaks up into a powder consisting of aggregates of very fine size and of a rather high specific gravity. For these reasons a certain proportion of even the best deposits, when used in the natural form, will not adhere to foliage nor will they spread well from blowers.

The author has conducted research for two years, on the utilization as an insecticide base, of a deposit found at Friant, California. A number of nicotine dusts have been developed with the unprocessed material as a base but unsuccessfully because of the irregularity of the particle size and the high specific gravity. Reconditioning the product by grinding, drying and screening gives standardized products of two or more grades of fineness. These are marketed under the brand name of *Frianite*.

Studies of the product have shown the following property: pH 6.8 to 6.9. This almost neutral reaction permits its use as a base for organic compounds, such as pyrethrum and rotenone solutions that are sensitive to alkaline reactions. The lack of chemical reaction with powders, such as standard lead arsenate, permits its use as a diluent without the danger of forming soluble arsenical compounds such as result from the use of hydrated lime.[1] There is also a lack of the drying action common on plants, from the application of hydrated lime.

The pinkish color of Frianite M3x permits its use as a colored diluent for roach and other powders, which a number of States now require to be "distinctly colored" to avoid confusing with powdered foods. The depth of color may not be sufficiently great to act as the coloring medium for white insecticides but will probably be sufficiently deep to avoid the necessity of adding other colors to the diluent or base.

A comparison of the rates of release of free and sulfate nicotine from the two grades used as bases for insecticidal dusts, M3x and D.S., show a consistently slower rate of release from the former (particle size 3.5 microns) than from the latter (particle size 5.65 microns.[2] This is shown in table 1, using a standard grade of hydrated lime as a basis for comparison.

Table 1.—Rates of release of nicotine.

MATERIAL USED AS BASE	NICOTINE FORM	RESIDUAL[1] NICOTINE
		Per cent
Hydrated Lime	Free	10
Hydrated Lime	Sulfate	18
Frianite D.S.	Free	8
Frianite D.S.	Sulfate	31
Frianite M3x	Free	15
Frianite M3x	Sulfate	41

[1] Percentage of residual nicotine found in the two *Frianite* dusts and hydrated lime following their exposure at varying lengths of time.

The above series of experiments were repeated three times at varying temperatures, 51° to 57°, 50° to 63°, and 55° to 72° F. The percentage of residual nicotine is given as averages of the three series since the reactions of the three carriers were consistent in each series. The procedure was similar in all instances, the liquid and dust being mixed in a ball mill, then standing to permit uniform penetration

[1] Hervey, G. E. R. and G. W. Pearce. The influence of lime on the toxicity of lead arsenate to cabbage worms. JOUR. ECON. ENT. 35: 554.

[2] Particle size determined by the air permeation method used by Dr. J. F. Kagy of the Dow Chemical Company.

of the insecticide, after which a very thin layer of the mixture was placed on sheets of paper and a gentle current of air allowed to flow over it. Following the exposure period the residual nicotine was determined. In all instances a slower release of nicotine was noted from the base showing the smaller particles, this factor being the principal difference between the two grades of *Frianite*.

From the standpoint of practical use it may be considered that the grade C.S. gives a quicker release of nicotine than does the M3x grade. The variation in the rate of evolution of nicotine is considered significant and gives the operator the choice between bases giving a very rapid and a slower rate of nicotine evolution.

The principal difference between the two grades of the product used being a variation in particle size, brings up the interesting question as to whether the perfection of modern grinding and separating equipment may yield dusts of such fine size and increased surface, as to actually give slower rates of evolution of adsorbed liquids than occurs with particles of larger size. The analogy may be similar to the variation in the drying rates of a sandy soil and the fine particles of a loam or clay soil.

SUMMARY.—Inert dust bases for insecticidal uses have been developed by grinding and separation into grades woich give varying rates of evolution of volatile insecticides. Such flexibility permits the use of a type best adapted to a desired rate of evolution.—7-6-43.

Effect of California Buckeye on Ants

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Beekeepers in California frequently suffer serious losses from the poisoning of their bees by nectar and pollen from California buckeye, *Aesculus californicus* (Spach) Nutt. The principal effect seems to be a reduction of egg laying and the production of abnormal brood (Burnside & Vansell, 1936). Since alcoholic extracts of California buckeye also have been found toxic to bees,[2] the suggestion was made that they might prove useful as a remedy for ants. Extracts of the nut and hulls were therefore tested against several species of common ants[3] found at Beltsville, Md.

Alcoholic extracts were made from samples of a flour that had been ground separately from the nut and hulls of buckeye at the Davis, Calif., laboratory of the Division of Bee Culture. The extract was fed to the ants dissolved at the rate of 1 part in 25 parts of a 1:1 honey-water mixture. Colonies confined in cages were fed the solution by means of glass tubes inserted through a hole in the side. No other food was given.

A colony of *Formica fusca* var. *subsericea* Say showed no ill effects from extract of the nuts after 1 month.

Two colonies of *Tapinoma sessile* Say fed extract of the hulls were unaffected after 17 days. Three other colonies, which were given extract of the nuts, were severely affected. Most of the workers were dead or paralyzed after about 12 days, but many of the paralyzed workers recovered. The queens were less affected. In one colony oviposition ceased and all the ants were dead after 16 days, but in another it proceeded normally and 37 days after the first feeding the colony contained 15 workers and young in all stages.

Two queenless colonies of *Tetramorium caespitum* (L.) that were given access to extract of the nuts after being starved for 2 days fed readily at first but soon refused to feed. About half the ants in one colony were dead after 6 days, and the others showed signs of paralysis although they recovered. The second colony, after feeding for awhile, refused the bait and died ultimately from starvation or desiccation.

A large colony of *Monomorium pharaonis* (L.) showed no ill effects from the extract of the hulls. When a small quantity of sirup containing the nut extract was placed near a nest in the greenhouse, the ants fed greedily at first but stopped after a couple of hours, and later moved their nest to a new location away from the sirup.

Under the conditions of these tests, the effect of the alcoholic extract of California buckeye on ants differed from that upon honeybees, for the adults only were affected, the brood continuing to develop normally. It appears, therefore, that alcoholic extracts of this plant would be of little value in controlling any of the species of ants used in these tests. The active principle of the buckeye nectar has not been isolated, but the toxic material seems to be mainly in the nut. It is possible that the method of extraction used did not get all of it out of the flour, or that some might have been lost in evaporation.—8-17-43.

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[1] Died January 4, 1942.
[2] Unpublished notes in the Division of Bee Culture.
[3] Identified by M. R. Smith of the Division of Insect Identification.

The Effect of Certain Chemicals on the Cherry Fruit Fly[1]

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Comparative laboratory chemical tests both with and without baits were conducted in 1939 on the white-banded cherry fruit fly, *Rhagoletis cingulata* Loew., which is a serious pest of cherries in Oregon. The purpose of the work was to compare tested and new chemicals against the fly in conjunction with baits.

Flies were taken from emergence cages at two day intervals and were caged where 10 per cent sucrose solution was available. After one day the flies were confined in groups of 10 in gauze-covered lamp chimneys for testing after the method of Boyce (1933).

The chemicals were sprayed on cherry leaves in the relations indicated in figure 1 until the spray dripped off. Chemicals were added to a 10 per cent sucrose solution "Bait" where sucrose is indicated. The sprayed leaves mounted in vials were allowed to dry and then a leaf was placed with each cage of flies. Contact chemicals were applied directly to the

[1] Published as Technical Paper No. 428 with the approval of the Director of the Oregon Agricultural Experiment Station. Contribution of the Department of Entomology.

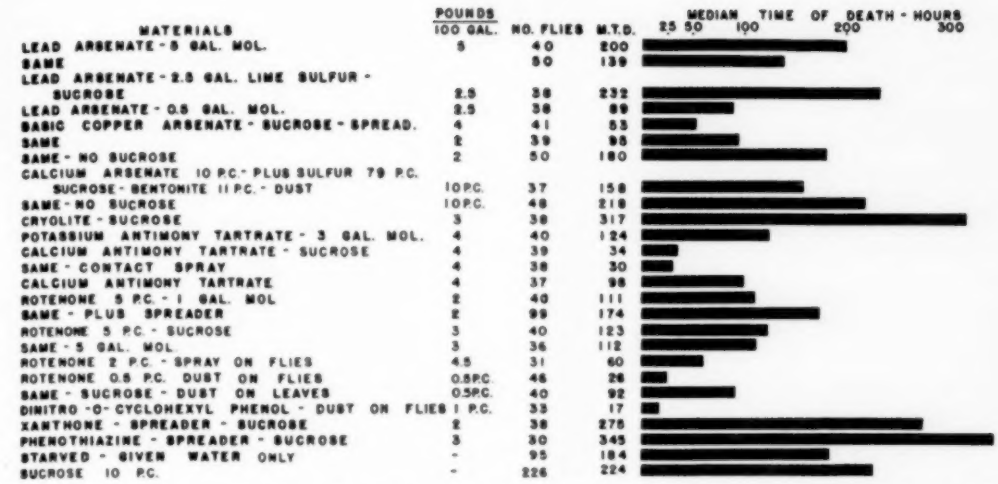
MATERIALS
POUNDS 100 GAL.
NO. FLIES
M.T.D.
MEDIAN TIME OF DEATH - HOURS
25 50 100 200 300
LEAD ARSENATE - 5 GAL. MOL. 5 40 200
SAME 5 80 139
LEAD ARSENATE - 2.5 GAL. LIME SULFUR - SUCROSE 2.5 38 232
LEAD ARSENATE - 0.5 GAL. MOL. 2.5 38 89
BASIC COPPER ARSENATE - SUCROSE - SPREAD. 4 41 53
SAME 2 39 95
SAME - NO SUCROSE 2 50 180
CALCIUM ARSENATE 10 P.C. - PLUS SULFUR 79 P.C. SUCROSE - BENTONITE 11 P.C. - DUST 10 PC. 37 158
SAME - NO SUCROSE 10 PC. 46 218
CRYOLITE - SUCROSE 3 38 317
POTASSIUM ANTIMONY TARTRATE - 3 GAL. MOL. 4 40 124
CALCIUM ANTIMONY TARTRATE - SUCROSE 4 39 34
SAME - CONTACT SPRAY 4 38 30
CALCIUM ANTIMONY TARTRATE 4 37 98
ROTENONE 5 P.C. - 1 GAL. MOL 2 40 111
SAME - PLUS SPREADER 2 99 174
ROTENONE 5 P.C. - SUCROSE 3 40 123
SAME - 5 GAL. MOL. 3 36 112
ROTENONE 2 P.C. - SPRAY ON FLIES 4.5 31 60
ROTENONE 0.5 P.C. DUST ON FLIES 0.5 PC. 46 26
SAME - SUCROSE - DUST ON LEAVES 0.5 PC. 40 92
DINITRO -O- CYCLOHEXYL PHENOL - DUST ON FLIES 1 P.C. 33 17
XANTHONE - SPREADER - SUCROSE 2 38 278
PHENOTHIAZINE - SPREADER - SUCROSE 3 30 345
STARVED - GIVEN WATER ONLY - 95 184
SUCROSE 10 P.C. - 226 224

FIG. 1. Toxicity of certain chemicals to *Rhagoletis cingulata* in the laboratory based on time of survival.

flies in a lamp chimney. Two jets of spray or puffs of dust from a small hand spray or dust gun were the contact doses. All chemicals were tested in spray form except those otherwise listed. A commercial spreader, *C77* consisting of a protein wetting agent was used at the rate of 5.5 ounces per 100 gallons of spray where mentioned. Dosages are given in pounds of dry material per 100 gallons of water or per cent of dry chemical in diatomaceous earth diluent. *Frianite* was the diluent for the dinitro dusts and bentonite was used with the calcium arsenate-sulfur mixture.

The measure of effectiveness was the length of time necessary for a chemical to kill 50 per cent of the flies. Flies were considered dead if they failed to move when their abdomen was pressed with forceps. The abbreviation "MTD" in the figure refers to the mean time of death which was the time required for 50 per cent mortality. "Mol" and "PC" refer to molasses and per cent respectively. Data were analyzed statistically by means of the Bliss (1937) time-mortality method. The resulting points were plotted and the MTD for each chemical was interpolated and graphed as shown in figure 1.

Commercial rotenone-bearing root was more effective as a contact spray than as a contact dust when dosage differences were considered. The effectiveness of rotenone-molasses spray was decreased by the addition of a spreader. DN, (2, 4-dinitro-6-cyclohexyl-phenol), in a walnut shell flour carrier was quite efficient in killing flies when used as a contact dust. One half gallon of molasses used with 2.5 pounds of lead arsenate gave an MTD of 89 hours while 5 pounds of the same chemical with 5 gallons of molasses gave MTD of 139 and 200 hours for an average MTD of 169 hours. Basic copper arsenate plus sucrose at 4 and 2 pounds resulted in MTD of 53 and 95 hours respectively, while without sucrose the MTD at 2 pounds was 180 hours. Ten per cent powdered sucrose by volume added to calcium arsenate-sulfur dust caused a 37 per cent decrease in the MTD. The sucrose used with calcium antimony tartrate resulted in a 65 per cent decrease in average killing time. A gallon of molasses equivalent to a 1 per cent concentration was similar in effect to 10 per cent sucrose when used as a bait with 5 per cent rotenone.

The most effective chemicals tested were rotenone, calcium antimony tartrate, and basic copper arsenate in spray form. The best contact dusts were DN and rotenone. The addition of a sweet "bait" noticeably decreased the MTD.—7-16-43.

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Nebraska Cattle Grub Survey[1]

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The scarcity of data on the actual extent of cattle grub infestation in Nebraska became evident during the winter of 1942–43 when a control program was being organized. Although there were some cattlemen who were acutely aware of the losses occasioned by this pest, there were many others who had given the problem little thought or who believed that infestation resulted largely from the importation of feeder cattle. More detailed information was obviously desirable in order to present an accurate and convincing account of the problem to the cattle growers.

Because of the many difficulties involved in the examination of large numbers of cattle on the range, it was considered more practical to examine cattle shipped to the packing plants in Omaha, and then to determine the location of the cattle at the time they became infested with grubs. Swift & Company, The Cudahy Packing Company, Wilson & Company, Armour & Company, various commission firms, and the National Live Stock Loss Prevention Board cooperated in the project. The hide cellar foreman of each packing company, whose experience had well qualified him for such an undertaking, kept records during February, March, and April on cattle grub

infestation of all lots of animals which had been maintained intact from the time of arrival at the stock yards until slaughter. The ownership of each lot of these cattle was then traced from the packer through the commission firms to the cattle feeder. Correspondence with the cattle feeder in some cases revealed the location of the cattle at the time infestation occurred. In many instances, however, the tracing of the origin of the cattle was too complicated to be practical. In spite of the difficulties associated with this procedure, it proved to be an inexpensive method of securing definite infestation records.

Records were obtained on 826 lots of cattle representing 26,776 different animals. Of these, 22,787 or 85 per cent were infested, *i.e.*, harboring at least one grub; 16,389 or 61 per cent were grubby, *i.e.*, harboring five or more grubs. Not a single lot of cattle was free from infestation.

Among the animals slaughtered at Omaha packing plants were included cattle which were on pastures in various parts of the Middle West and West during the previous season when adult flies were depositing eggs. In view of this fact the above data, taken as a whole, can be assumed to represent the average infestation for cattle shipped to Omaha without reference to place of origin. It was definitely determined, however, that 60 lots which included 1843 cattle, representing all sections of the state, were obtained directly from Nebraska farms and ranges. Among these, 92 per cent were infested and 64 per cent grubby.—8-26-43.

The Rôle of Mating in the Reproduction of Parasitic Hymenoptera

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In many bisexual species of Hymenoptera, reproduction is uniparental; that is, all females, as well as all males, develop from unfertilized eggs. Under such conditions mating not only is unnecessary, but may even lower the reproductive capacity of the female. In the other bisexual species of the order, however, reproduction is biparental, and mating is necessary for the determination of the female sex, since parthenogenesis is limited to the production of haploid males. No species of Hymenoptera are known in which normal males develop from fertilized eggs.

Mating involves the transference of sperms from the seminal vesicle of the male to the sperm capsule of the female. In many species of insects, mating is influenced by the presence or absence of live sperms in the sperm capsule. As pointed out by Wigglesworth (1940), the gonads of insects, unlike those of many other animals, have little if any influence on mating.

It is of interest to note that Gowen & Nelson (1942) recently stated that "In the past the sex of the offspring from any mating has been a matter of chance" and that ". . . no method of sex control has stood the scrutiny of unbiased investigation." These authors may have overlooked the fact that in species in which unmated females produce only haploid offspring, the female sex is predetermined by fertilization of haploid eggs, as demonstrated in 1845 by Dzierson. This phenomenon permits the manipulation of sex production in the Hymenoptera (Brunson 1937; Clausen 1939; Flanders 1939b). For a number of years entomologists engaged in the mass production of parasitic Hymenoptera have controlled the sex of the individuals either by permitting or preventing mating, or by providing the mated breeding stock with hosts which differ in their stimulating effect on the spermatheca of the female parent (Flanders 1939a).

The preponderance of one sex obtained by thus controlling fertilization in biparental species is not influenced by lethal factors. Under conditions favorable for oviposition, the normal numbers of individuals are produced, the sex of each having been predetermined.

Mating may be detrimental in species in which reproduction is uniparental, for, should a diploid egg be fertilized, it may not hatch as a result of its triploid condition. Males rarely appear in cultures of *Encyrtus fuliginosus* Comp., for example, but when a male is present, mating readily takes place. With *Habrolepis rouxi* Comp., on the other hand, though half of the population may consist of males, mating never takes place, the female not reacting to the courting activity of the male.

In species that oviposit as readily before as after mating, the sex ratio of the progeny of a female may be determined by the time of mating. This is the case with such species as *Coccophagus lycimnia* (Walker), which oviposits ectoparasitically on chalcidoid larvae before mating and endoparasitically in lecaniine scale insects after mating (Flanders 1937). Whether mated or unmated, the female of such a species deposits its complement of eggs. If she is mated immediately after emergence, all her adult progeny are females; if she remains unmated, all her adult progeny are males.

In many species of Aphelinids mating causes a change in the oviposition instincts of the female, oviposition being hyperparasitic before and parasitic after mating.

In many species of parasitic Hymenoptera, however, mating is a prerequisite of total oviposition, and the sex ratio is determined by environmental stimuli. Parker & Thompson (1928) noted that with *Melittobia acasta*, repeated matings of the female are necessary for the deposition of her complement of eggs. Schmeider (1938) found that when the female of *M. chalybii* is mated with a different species, the oviposition response is the same as if mated with a male of its own species, but that in such a case the fertilized eggs are not viable. The females of the uniparental generation of the gall fly, *Neuroterus lenticularis*, deposit practically all their eggs after mating. The eggs are deposited in plant tissues that apparently inhibit the development of haploid eggs, since only females develop (Doncaster 1917). It should be noted that the fact that mating is a prerequisite of oviposition is not proof that female progeny are derived from fertilized eggs.

In any species of parasitic Hymenoptera in which oviposition is influenced by mating, unmated females are likely to deposit a greater proportion of nonviable eggs than mated females. An extreme case was observed by Schmeider (1938), who found that the unmated females of *Melittobia chalybii*, if they oviposit at all, lay only a few eggs, most of which do not hatch.

It is significant that the inhibition of oviposition in *ectoparasitic* Hymenoptera is counterbalanced by the absorption of the ripe eggs in the ovary. The absorption of such eggs is completed within a few hours (Flanders 1942). Partially absorbed non-viable eggs may be deposited.

The occurrence of oosorption in *Melittobia acasta* would account for the fact, first noted by Smith (Howard & Fiske 1911) that unmated females turgid with eggs produce only a few male offspring and that the number of these is about equal to those males which would have been produced had the female been mated.

In certain species, inbreeding may tend to inhibit oviposition. According to Whiting (1940), the hatchability of the eggs of *Microbracon hebetor* is about 80 per cent for unmated and for out-crossed females and about 50 per cent for close-crossed females. Fewer fertilized eggs are deposited by close-crossed females than by out-crossed females. In inbred stocks, some females deposited many sterile eggs, others deposited none. Embryonic development may continue for a time in almost every egg that fails to hatch. Failure of many eggs to hatch may not result from fertilization, although the decrease in hatchability of eggs from inbred stocks appeared to be limited to fertilized eggs.

With many parasitic Hymenoptera, the female, once mated, may never regain its mating instinct. This may be an effect either of an adequate store of sperms or of aging. The influence of aging has been observed in the female of *Pachycrepoideus dubius*. If not mated within five days after emerging from its host, the female usually does not respond to mating stimuli (Crandell 1939).

SUMMARY.—In those species of parasitic Hymenoptera in which reproduction is uniparental, mating may cause a reduction in the number of viable eggs. Where reproduction is biparental, mating is necessary only for the production of females. In species in which oviposition occurs as readily before as after mating, the time of mating determines the sex ratio. In species in which mating precedes oviposition, the completeness of oviposition and, consequently, the amount of oosorption and the proportion of sterile eggs deposited are determined by the mating. In some cases inbreeding may reduce the proportion of viable fertilized eggs.—6-1-43.

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An Observation Box for Solitary Bees and Wasps

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It has always been difficult to make detailed observations on the solitary bees and wasps that normally build nests in hollow twigs or brambles where their development cannot be easily followed. The Raus suggested cutting patches of sumachs and blackberries to provide homes for these insects as they readily appropriate severed stems. However, such nests must be torn apart to make careful observations. Hicks, also Balfour-Browne,[1] used test tubes of various sizes as artificial methods of rearing and studying solitary insects. With these suggestions the writer proceeded to build an "apartment house" for solitary bees and wasps. A box measuring 2.5×6.5×12 inches was constructed. A series of eight holes, a half-inch in diameter, were bored in the front board which was 2.5×12 inches. A second board of similar dimensions and with corresponding holes was placed about one third the distance from the back of the box. These two boards support a series of glass tubes with 8 and 10 mm. bores. The outer ends of these tubes, when in place, were flush with the outside of the front board. The box was inclosed on all sides so that the tubes, with the exception of their outer ends, were completely in the dark. A sliding door, 2 inches wide, at the back of the box permitted easy observation of the inner portions of the tubes and facilitated removing the tubes for further observation. It is well to have the tubes cut square at both ends so that they fit flush against the back of the box and make a neat opening at the front of the box. The box was painted white to match the house upon which it was fastened. The paint also made the job more permanent.

The success of this observation box can be judged

[1] Balfour-Browne, F. (1925) Concerning the habits of insects. Cambridge Univ. Press.
Hicks, C. H. (1937) Notes on rearing solitary bees and wasps. In Cultural Methods for Invertebrate Animals. Comstock Pub. Co.

by the visiting insects that were attracted during the summer of 1943. Incidentally, this project was stimulated by gas rationing and the difficulty of making extended trips. It afforded an opportunity of becoming intimately acquainted with some common back-yard insects. The box was fastened at a convenient level, about five feet from the ground. This was finished and ready for occupation by May 1.

On May 9 a species of *Osmia* visited the box. Several days previous to this date, these bees were quite numerous on the blossoms of the red bud, *Cercis canadensis*, growing not more than 15 feet from the observation box. For some reason the glass tubes did not prove entirely satisfactory to them. They entered every tube and built mud partitions but only three cells were provisioned with pollen and sealed. On June 28 the larvae were nearly mature and the glass tubes were removed and replaced with clean tubes so that other species, which seemed to be hunting places to nest, could use the spaces.

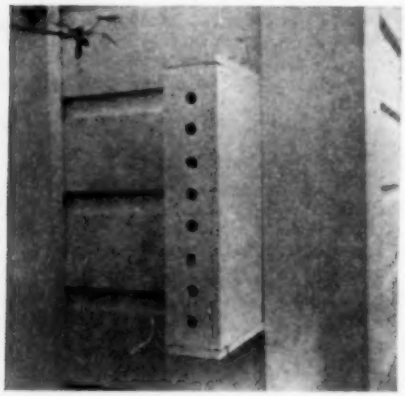

FIG. 1. An observation box for solitary bees and wasps.

On June 27 a female *Megachile latimana* selected one of the glass tubes in which to build her nest. This species had been cutting leaves as early as June 18 so it is evident that some females had been making nests elsewhere. From June 28 to July 5 five cells were made in one of the tubes. On the latter date the female was busy packing the outer end of the tube with pieces of leaves.

On June 29 a female *Chlorion* (*Isodontia*) *harrisi*. Fern., started a nest in one of the glass tubes. She placed a green grasshopper of the genus *Orchelimum* in the tube and attached an egg to it. The outer end of the tube was nearly half filled with shredded grass. At the time, the wasp was resting in the outer end of the tube. She was killed for identification and observations ceased.

From June 26 to July 20, *Monobia quadridens* showed considerable "interest" in these tubes. Notes on the habits of this species will be published elsewhere. During this period apparently the same wasp occupied five of these tubes and constructed 11 cells. She was still building cells and provisioning them when this paper was completed.

Trypoxylon clavatum was attracted to a second box of similar design, but placed in the woods. The first week there was no evidence of activity but by the end of the second week, on July 16, the inner end of every tube was sealed with mud and one of them contained three cells provisioned with small spiders. Several wasps were hovering about the box when it was visited and there was evidence that these wasps were taking full possession of the observation box. The following week two more tubes were packed with cells and plugged at the outer ends with mud.

Tubes of different bores can be used to attract various species. *Osmia* selected tubes of 8 mm. bore. *Chlorion*, *Monobia* and *Trypoxylon* selected those of 10 mm. bore. Tubes of these sizes seemed to attract most of the common solitary bees and wasps.

The observation box is an excellent way of watching the activities of solitary bees and wasps, of determining the provision used, of ascertaining methods of partitioning, etc. However, it may not be entirely satisfactory for rearing the larvae of these insects. Moisture from the provision collects on the interior of the glass tubes and creates an unnatural condition. In brambles or the cavities of wood borers, the walls of the burrows absorb this moisture.—8-4-43.

The Date-Stone Beetle in California and Lower California

E. GORTON LINSLEY, *University of California, Berkeley*

The date-stone beetle, *Coccotrypes dactyliperda* (Fab.)[1] (Fig. 1) has been reported from North America a number of times but there has been some question as to whether or not it has actually been established. As early as 1889, Hamilton reported that it was sometimes brought into the United States in dates and areca nuts but he made no claim that it was established anywhere in the country. Blandford (1895–1905), in the Biologia Centrali-Americana, makes essentially the same statement for Mexico and Central America. Van Dyke (1927), however, has reported it from Los Angeles, where it was breeding in the seeds of the Canary Island Palm, *Phoenix canariensis*. At that time he expressed the hope that it would not become established in the date growing areas of Southern California. However, Mr. Perez Simmons (*in litt.*) reports that he and his colleagues found the species in 1932 and 1934 infesting waste dates collected from the ground near Indio, California.

Recently the writer has examined samples of dates from Lower California which were heavily infested with the date-stone beetle. The dates were grown at Loreto, Lower California. They were harvested in October, 1942, marketed at Guaymas, Mexico in April, 1943, and imported into California about May 1, 1943. When examined by the writer on May 30 every date in the sample was infested and showed from one to twenty-three perforations. The seeds contained all stages of the beetle although by far the majority of the individuals were adult.

A native of the Old World, the date-stone beetle is known in Africa, southern Europe, and Asia as a pest of the date, *Phoenix dactylifera*, betel nut, *Areca catechu*, and the Doum-Palm, *Hyphaene* sp. (Hagedorn, 1913; Van Der Merwe, 1923; Squire, 1935, et al.). Speyer (1918) has recorded the species entering nuts of nutmeg, *Myristeca fragrans*, in Ceylon, and de Sanabria (1921) has reported infestations of date palm and sabal palm, *Sabal palmetto*, in Ecuador. This last record, however, may be based on another species. Swezey (1928, 1936) has reared it from

[1] Kindly identified by Dr. M. W. Blackman, Division of Insect Identification, Bureau of Entomology and Plant Quarantine, Washington, D. C.

Phoenix dactylifera, Livinstona chinensis, L. rotundifolia, Oreodoxa regia, Washingtona filifera, and *Pritchardia pacifica* in the Hawaiian Islands. He regards it as of no economic importance in that area since it attacks seeds only while they are lying on the ground. Simmons apparently believes that the same is true in Southern California.

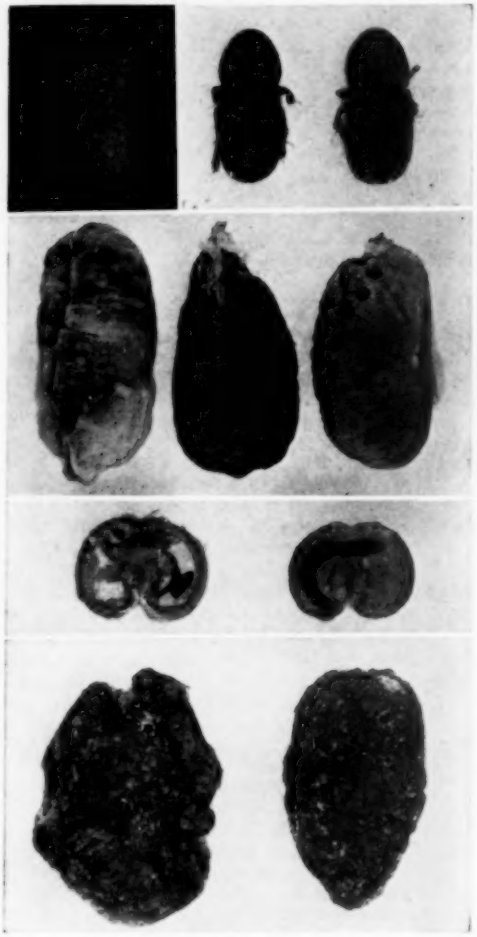

FIG. 1.—The date-stone beetle and its work.

In Lower California it would appear that the beetles attack the mature dates while they are being sun-dried. They perforate the surface and tunnel inward to the stone. The stone is penetrated, the boring dust and excrement ejected, and communal galleries formed within (Fig. 1). In these galleries adults, larvae, pupae, and eggs may all be found together. In North Africa, Willcocks (1914) reported finding 9 adults, 6 pupae, and 24 larvae in a single date-stone. Swezey (1928) gathered 38 seeds containing a single boring from under one Hawaiian palm tree. Later, in an 8 day period, 3518 adults issued, averaging 92 individuals per seed.

The importance of this insect as a pest of commercial dates in Lower California is not yet clear. If, as seems likely, the green fruit is not attacked on the tree, then reducing the drying period to a minimum, offering protection to the fruit during drying and an adequate fumigation before packing should prevent serious injury. In southern California, commercial practice is such as largely to prevent infestation. The dates are rarely sun-dried but are picked when nearly ripe and quickly transferred to packing houses for sorting and processing.—7-7-43.

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Toxicity of Anabasine to the Citrus Thrips

E. A. MCGREGOR, *Whittier, California*

The writer has tested free anabasine, 1:1000 and 1:2000, and anabasine sulfate, 1:600 and 1:800, with and without sugar, against the citrus thrips in the laboratory. This was done by placing adult thrips in cages containing lemon leaves with dried deposits of the solutions. Sugar-containing residues (excepting the 1:2000 dilution) from freshly deposited to 3 days old, gave mortalities of from 99.1 to 100 per cent in from 1 to 4 days. Deposits of free anabasine, 1:2000, and sugar killed 78 per cent of the thrips in 4 days. Residues of free anabasine, 1:1000, without sugar, gave mortalities of from 60 to 100 per cent in from 2 to 4 days.

A manuscript presenting the complete results of these studies will appear later.—8-4-43.

An Outbreak of the Snipe Fly *Symphoromyia hirta*[1]

HARLOW B. MILLS, *Montana State College*

The females of several species of snipe flies of the genus *Symphoromyia* have been known to attack humans in this country since the observations of Osten Saken in 1877. The occasional references in the literature to these insects as blood suckers are no measure of the intense misery which they can at times inflict.

The females have well-developed tabanoid mouthparts as has been shown by Knab & Cooley (1912), Ross (1940), Snodgrass (1943), and others.

In the summer of 1943 *Symphoromyia hirta* Johns. was extremely abundant in the mountains of southwest Montana. On the 10th of July several flies were seen just above the mouth of Portal Creek on the Gallatin River in Gallatin County. On the 24th they were extremely abundant on Fawn Creek, just inside the northwest corner of Yellowstone Park. It was estimated that there were from three to four hundred swarming about and alighting on each member of a fishing party on that stream. Approximately fifty were observed on the back of one of the men.

The nuisance which they caused was of two types. Occasionally they bit savagely, leaving a drop of blood at the wound. Bites were most commonly sustained on the wrists, the palms of the hand, and the neck. There seemed to be considerable individual variation in reaction to these bites. There was consistently an immediate burning sensation following the penetration of the mouthparts through the skin, but in the case of one in the party this was followed by no local irritation, while with another the bites were marked for a couple of days by inflammation, swelling, and itching, similar to the common reaction to bedbug attacks. Several individuals were noted attempting to penetrate a leather jacket. While the attacks were vicious and painful there seemed to be some fewer of them than would have been sustained from an equal number of *Chrysops* or *Tabanus*.

Other than for their biting, their actual numbers, persistence, and lethargic action after they had settled were of considerable annoyance. They crawled up sleeves, down shirt collars, impeded vision by alighting on glasses, and were actually inhaled. When a gust of wind came by they would drop down on backs and shoulders in swarms, hovering again when the wind quieted.

On July 27 a cow elk was seen in the Madison River a few miles east of West Yellowstone, so busily engrossed in fighting the flies that she paid no attention to cars passing along the road beside her. On approximately the same date campers on the Taylor's Fork of the Gallatin came upon a deer standing in the water, so affected by the attacks of the flies that it allowed very close approach.

By August 7 the numbers of flies had greatly diminished and, where two weeks before they had discouraged people from going out along the streams, there were very few in evidence. On August 19 and 20 none was in evidence.

There is no reason to believe that snipe flies might not function as various species of tabanid flies do in the transmission of such diseases as tularaemia, and under conditions as they existed in southwest Montana for a period during the summer of 1943 they would be much more likely to do so.

[1] Diptera, Rhagionidae.

The periodical importance of these insects in mountainous areas of the West should not be underestimated, but fortunately they seem to be restricted to higher elevations and mountainous terrain. None was noticed in 1943 below an elevation of 5000 feet. Cooley (Knab & Cooley, 1912) states "It is my impression that it is distinctly a mountainous form; that is, we do not find it in our large open valleys, but only in mountainous places." Further, Ross (1940) says of the related *S. atripes* Bigot in the Cascade Mountains of British Columbia "In that part of the country hikers agreed that at elevations of about three to five thousand feet the discomforts caused by this fly were equalled only by those of mosquitoes. . . ."

No formal experiments were carried on to discover or test repellents against *S. hirta*, but it was noticed that some protection of rather brief duration was obtained with the liberal use of oil of citronella; and tobacco smoke tended to discourage those hovering about the face.—9-27-43.

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Dichlorethyl Ether for Cabbage Maggot Control

W. H. LANGE, JR., *California Agricultural Experiment Station, Berkeley*

The growing of increased acreages of cabbage for dehydration and market in the Salinas Valley of California resulted in a severe cabbage maggot, *Hylemya brassicae* (Bouché), problem during May and June, 1943. Injury was confined chiefly to cabbages in seed beds and in most instances the maggots were already causing injury before any control measures were initiated. The use of the usual mercury materials did not prove of much value.

Beta-beta-dichlorethyl ether (CL $CH_2CH_2OCH_2$-CH_2CL) used at the rate of 20 cc. to 1 gallon of water and 0.4 cc. of a sodium sulfate of a higher synthetic secondary alcohol (*Tergitol 7*) was found to kill the maggots and act as a repellent for a limited period of time. Dosages of 5, 10, 20 and 40 cc. were applied to cabbages in seed beds of from 4 to 8 inches high with no visible injury. Apparently cabbage is very tolerant to the material.

Different dosages were tried, but in light sandy soils a dosage of 8.5 ounces of the emulsion to a lineal foot of cabbage row in the seed bed gave from 80 to 99 per cent control of the maggots. In heavier types of soils more material was needed.

The material was applied to the bases of the plants by compressed-air sprayers which had the spray nozzles removed. Care should be exercised to emulsify the material adequately before applying.

Commercial ready-mix preparations, such as those prepared for lawn moth control (usually containing 96 per cent of dichlorethyl ether plus emulsifier), were found satisfactory when used at the dosage previously mentioned.—8-31-43.

The Potato Tuber Worm, a Host Suitable for Mass Production of *Macrocentrus ancylivorus*

STANLEY E. FLANDERS, *University of California Citrus Experiment Station, Riverside*

Upon the discovery of the oriental fruit moth, *Grapholitha molesta* Busck, in southern California in the fall of 1942, the Division of Beneficial Insect Investigations of the University of California Citrus Experiment Station, under the direction of Professor Harry S. Smith, began preparations for the mass propagation of the parasitic braconid *Macrocentrus ancylivorus* Rohwer. A laboratory host that could be produced cheaply and continuously throughout the year was desired. Several possible hosts were tested, among them the potato tuber worm, *Gnorimoschema operculella* (Zell.). This worm long has been a pest in the insectaries of southern California in which the potato is used as a food plant for various coccids. It was obvious that the potato tuber worm would be an ideal host if parasitization by *M. ancylivorus* occurred readily.

In the spring of 1943, by arrangement with the Federal Bureau of Entomology and Plant Quarantine, a stock of *Macrocentrus ancylivorus* adults were sent to Riverside, California, from Moorestown, New Jersey. Reproduction occurred on potato sprouts infested with larvae of the tuber worm. Subsequently it was found that *M. ancylivorus* would oviposit with equal readiness in larvae in potato tubers. Mass production was under way by August, 1943.

Dr. Allen states (*in litt.*) that at Moorestown the possibility of using the potato tuber worm as a host for *M. ancylivorus* was considered several times but was ruled out because of lack of local infestation.

Macrocentrus ancylivorus was established in California prior to 1938, having been reared from *Melissopus latiferreanus* (Wasm.) infesting acorns in Del Norte County and Catalina cherries in Santa Barbara County (Dohanian, 1942).—8-16-43.

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DR. H. D. YOUNG RETIRES

The many friends of Mr. Harry D. Young will regret to learn that on account of total disability he retired on July 1, 1943, from the Bureau of Entomology and Plant Quarantine of the U. S. Department of Agriculture after having served for 26 years in the Federal Government. In November, 1941, Mr. Young suffered a severe attack of phlebitis and had never fully regained his health.

Mr. Young is the author of about 25 publications dealing with insecticidal fumigants. In cooperation with other workers in this Bureau, he devised an improved apparatus for the rapid vaporization of carbon disulfide, and an improved sulfur burner for fumigating mushroom houses with sulfur dioxide; determined the vapor pressure of many fumigants; studied the evolution of hydrocyanic acid from calcium cyanide, the effect of fumigants on the germination of seeds and the popping quality of corn, the vacuum fumigation of flour products and the fumigation of flour mills with hydrocyanic acid; and developed certain new fumigants.

Mr. Young is joint inventor with Dr. R. T. Cotton of the ethylene oxide-carbon dioxide mixture now used extensively for fumigating spices and dried fruits. The National Archives in Washington, D. C., uses this mixture to kill insects infesting valuable papers and books.

In recognition of his contributions to the protection of grain and cereal products against insects, Mr. Young jointly with R. T. Cotton and R. C. Roark in February, 1940, received a Modern Pioneer Award from the National Association of Manufacturers.

DR. WALTON RETIRES

William Randolph Walton, Senior Entomologist of the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, has retired upon reaching the age of seventy years, effective October 1, after exactly thirty-three years of service. All of this has been in the Division of Cereal and Forage Insect Investigations in which for seven years he was Division leader. The program of investigations by the Bureau of the European corn borer was inaugurated and for several years was conducted under his direction. In addition to specialization in control of insects attacking cereal and forage crops, he also made noteworthy contributions to the literature on parasitic Diptera, including "An Illustrated Glossary of Chaetotaxy and Anatomical Terms Used in Describing Diptera," which has been widely useful in its field. On his retirement some sixty of his colleagues were present at an informal lunch at the Department of Agriculture in his honor, at which they expressed by suitable gifts their good wishes and high regard for him.—9-20-43.

ASSOCIATION TO HOLD ANNUAL MEETING IN COLUMBUS

The annual meeting of the Association will be held in Columbus, Ohio, on December 7, 8 and 9, 1943. Headquarters will be in the Deshler Wallick Hotel.

A very excellent program is being arranged in cooperation with the Entomological Society of America. The program will center around current problems and will be so arranged as to permit all who wish to do so to participate in the discussions. Business sessions will also be held and will be of more than usual importance

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Annual Meetings for 1943

THE 1943 ANNUAL MEETINGS of the American Association of Economic Entomologists will be held in Columbus, Ohio, December 7 to 9. The decision to hold the meetings this year was reached only after careful consideration by the Executive Committee and after consultation with the officers, many of the chairmen of standing committees, and a considerable number of other members of the Association. The decision was not unanimous, but based on the feeling expressed by many that these meetings are essential to maintain needed contact between workers and to supply necessary information in furtherance of the war effort.

There has never been a time in the history of American entomology when informed, cooperative action by entomologists was needed more than now. Because of shortages of materials and equipment for insect control, it has been necessary to establish governmental control over certain production facilities and over distribution of certain essential materials. Many entomologists have contributed to the extent of their ability information and other assistance to supply a background on which responsible agencies may base intelligent action for the public good. Many who have assisted in furnishing this information have had no opportunity to familiarize themselves with the over-all situation or to learn in what way the assistance which they have been rendering has been of importance or how it may be made more valuable in the future.

One of the most important problems before American entomologists is to prevent insect losses to food crops under the handicap of limitations induced by war necessity on insecticides, equipment, and labor for insect control. Actions to regulate the use and distribution of certain materials have been taken to assure the maximum usefulness of the supplies available for the protection of food crops and have been forced by the supply situation. No one believes that these various actions have been free from error. In fact, many errors are recognized frankly by everybody who has been concerned with this important and essential operation. That the errors have not been more serious has been due largely to the cooperation which has been willingly furnished by entomologists in estimating the quantities of materials needed for the control of insects and the relative importance of these insects from the standpoint of the over-all production picture. Much improvement is needed in the accumulation of information and in the intelligent application of the facts now available to the problem at hand. This can be obtained only if the entomologists responsible understand the need for the actions taken and the type of information which is required to make these actions intelligent and effective.

It has been recognized that any estimate of requirements, for either supplies or materials, is subject to gross seasonal variation according to the occurrence of insect outbreaks and their extent. Many entomologists have assisted in maintaining a current picture, as far as possible with the manpower available, of the status of insects which are likely to require the largest amount of critical insecticidal materials for their control. Surveys of the status of important pests have been conducted in many states as a result of effective cooperation between the Bureau of Entomology and Plant Quarantine and state entomological workers. This current information has made it possible for industry to distribute the insecticides which are available so that they will be on the ground at the critical places in accordance with current conditions, and has avoided largely the errors which would be inherent in distribution made solely on an historical basis. The whole problem of maximum production of food and materials as it relates to the national welfare and to the welfare of the world is one of far more than local or even national interest. It requires again a joint attack and maximum utilization of facilities by all entomological agencies if huge losses of food supplies are to be avoided.

All entomological activities are hampered by the limitations on manpower. The cooperative consideration of pressing regional and national problems, in order to utilize to the full all the entomological

manpower available, is of the greatest concern under present conditions if the national responsibilities of the entomological profession to the war effort in the protection of food and other agricultural materials are to be met.

The field of medical entomology in safeguarding the military and public health from hazards arising through insects which transmit serious diseases has assumed a prominence much greater than normally has been attributed to it. Unusual demands have been made on research institutions for practical knowledge which will assist the military organizations in meeting the problems presented to them by the new situations inherent in the far-flung activities of a global war. Just what these problems are, and what information is lacking to meet them, are topics of interest to the entire entomological profession and have never been presented to it in an authoritative way since the outbreak of this war.

These problems were considered by the Executive Committee and it felt that the opportunity to discuss them and to obtain a coordinated approach as far as possible was of such significance that the 1943 meetings should be held even in the face of travel restrictions and the overburdened transportation facilities. The Entomological Society of America decided to join with the American Association of Economic Entomologists in these meetings and the program committees of the two organizations have been combined. This committee was requested to organize a program departing from the usual style of the national meetings with no routine reading of research papers but with speakers, who are particularly qualified, invited to present information which it is believed should be available to entomologists, ample time being provided for discussion.

This combined committee has arranged a program consisting of invitation papers and discussions based on them covering topics of special prominence in the general fields of medical and agricultural entomology in wartime. The committee has worked diligently and, in spite of the severe handicaps of the times and the novelty of the meeting planned, has succeeded in organizing what promises to be a valuable and instructive program. The Association is indebted to a number of its own members and to men who are not members of either organization, who have agreed to present papers and to lead discussions. Much of the success of the program will depend on the members of the Association entering into these discussions.

It is hoped that as many entomologists as can do so, considering the travel restrictions under which we all are operating, will attend these meetings and contribute to the solution of the important questions which are before the entomological profession in these trying times.

P. N. ANNAND
Washington, D. C.

PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL MEETING

PACIFIC SLOPE BRANCH

AMERICAN ASSOCIATION OF ECONOMIC ENTOMOLOGISTS

Oregon State College, Corvallis

June 16–18, 1943

The 28th Annual Meeting of the Pacific Slope Branch was the second one held under war conditions, and even though the attendance was again reduced, the meeting was very well worth while.

The main address on "A Century of Entomology in the Pacific Northwest" was made by Dr. Melville H. Hatch of the University of Washington. He very ably presented the history of entomology in the Pacific Northwest, from the earliest records to the present day.

The papers presented during the day and a half session covered various phases of entomological work being carried on in the west, including reports on some of the special projects inaugurated since the start of the war.

A colored motion picture "Guardians of Plenty" by duPont Company, was an excellent presentation of methods of pest control research.

Dr. E. F. Phillips reported on the progress made by the Committee on the Coordination of Entomology with the War Effort. This committee has been very active and is doing a remarkably successful piece of work.

Vice President A. S. Hoyt represented the main association at the meetings. He brought a message from President Annand, and discussed some of the work entomologists are doing in connection with the war effort.

An informal smoker was held the evening before the meetings began, and provided a very pleasant

opportunity to visit and renew acquaintance with members from the different parts of the country.

After an excellent turkey dinner at the H-Bar-H Ranch, Dr. K. L. Gordon of Oregon State College showed some of his own colored motion pictures of animals in the Yellow Pine country.

Resolutions Committee Report

BE IT RESOLVED, that the Pacific Slope Branch of the American Association of Economic Entomologists express its appreciation to President A. L. Strand of the Oregon State College for his interest and consideration in contributing to the success of the 28th Annual Meeting at Corvallis.

BE IT RESOLVED, that the Pacific Slope Branch express its appreciation to the committee on local arrangements under the direction of Professor Don C. Mote, to the Benton Hotel, to Dr. E. G. Quesinberry, to Dr. George B. Cox, to Dr. K. L. Gordon, and to others who have contributed towards the excellent arrangements which have made possible the success of the 28th Annual Meeting.

BE IT RESOLVED, that the members of the Pacific Slope Branch express its appreciation to the officers for their excellent conduct of the affairs of the organization during their term of office.

WHEREAS, it is evident that the discussions and interchange of ideas at this 28th Annual Meeting have definitely contributed to the value of Entomologists in the War effort,

BE IT RESOLVED, that the regular summer meeting be held and:

BE IT RESOLVED that the officers of the Branch be authorized to designate the place and time for such meeting.

WHEREAS, the members consider that a meeting of the entomological organizations essential to the fullest utilization of the efforts of the entomologists and the successful prosecution of the war,

BE IT RESOLVED, that the Pacific Slope Branch urge the executive committee of the American Association of Economic Entomologists to make plans for a National meeting for the current year.

WHEREAS, limitations of proportion of active ingredients in certain insecticidal mixtures have been placed at levels which seriously reduce the effectiveness of the mixtures.

BE IT RESOLVED, that restrictions of this nature are not considered advisable.

WHEREAS, different laws and regulations governing the sale and use of insecticides in the Pacific States conflict, which results in complicating pest control,

BE IT RESOLVED, that the Pacific Slope Branch recommends that the Western States strive for uniformity in insecticide and pest control laws.

Resolutions Committee:

A. E. Michelbacher
Charles F. Doucette
Esler Johnson

June 18, 1943
Corvallis, Oregon

Treasurer's Account (*Condensed*)

1942–1943

May 29, 1942	Balance on hand		$32.83
June 13, 1942	Express on film and programs	$ 1.35	
Aug. 28, 1942	Refun dfor 1941–42 expenses.		31.78
Nov. 8, 1942	Stamps	1.84	
April 1, 1943	Printing and mailing notices and programs	61.62	
April 19, 1943	Telegram to Local Chairman.	1.00	
			$64.61
	Overdrawn		1.20
		$65.81	$65.81

APPROVED BY AUDITING COMMITTEE

Pacific Slope Branch

Of the total attendance of 60, the following members were present:

Alexander, C. C., Yakima, Wash.
Allen, P. B., Yakima, Wash.
Braucher, R. S., Riverside, Calif.
Crawford, H. J., Chico, Calif.
Chamberlin, J. C., Forest Grove, Ore.
Campbell, Roy E., Alhambra, Calif.
De Sellen, F. E., Olympia, Wash.
Doucette, Chas. F., Sumner, Wash.
Dohanian, S. M., Eugene, Ore.
Doyle, E. T., San Francisco, Calif.
Eagleson, Craig, Portland, Ore.
Eichman, R. D., Pullman, Wash.
Furness, R. L., Portland, Ore.
Ferguson, E. G., Corvallis, Ore.
Fulton, R. A., Whittier, Calif.
Fenton, Alfred, Houston, Texas
Gardner, Leo R., Berkeley, Calif.
Gray, K. W., Corvallis, Ore.
Gentner, L. G., Talent, Ore.
Grady, H. J., Portland, Ore.
Hawkins, Lon A., Eugene, Ore.
Hoyt, A. S., Washington, D. C.
Hatch, Melville, Seattle, Wash.
Herbert, Frank B., San Francisco, Calif.
Johnson, Esler, San Francisco, Calif.
Jones, Paul R., San Francisco, Calif.
Jones, E. W., Walla Walla, Wash.
Jones, S. C., Corvallis, Ore.
Keen, F. P., Berkeley, Calif.
Lane, M. C., Walla Walla, Wash.
Litooy, Ed., San Francisco, Calif.
Mote, Don C., Corvallis, Ore.
Michelbacher, A. E., Berkeley, Calif.
Morrison, H. E., Corvallis, Ore.
Newcomer, E. J., Yakima, Wash.
Phillips, E. F., Ithaca, N. Y.
Porter, B. A., Washington, D. C.
Roark, Lenox, Seattle, Wash.
Rockwood, L. P., Forest Grove, Ore.
Rolfs, A. R., Wenatchee, Wash.
Robinson, R. H., Corvallis, Ore.
Rideout, H. L., Yakima, Wash.
Rosenstiel, R. G., Corvallis, Ore.
Schuh, Joe, Corvallis, Ore.
Scullen, H. A., Corvallis, Ore.
Thompson, B. G., Corvallis, Ore.
Vertrees, J. D., Portland, Ore.
Webster, R. L., Portland, Ore.
Yates, W. W., Sherwood, Ore.

The new officers elected were:

Chairman: A. F. Flebut, *San Francisco, Calif.*
Vice-Chairman: W. M. Hoskins, *Berkeley, Calif.*
Secretary-Treas.: Roy E. Campbell, *Alhambra, Calif.*

The treasurer's report and all committee reports were approved by unanimous vote.

Roy E. Campbell, *Secretary*

OBITUARIES

George Ethelbert Sanders, 1884-1943

George Ethelbert Sanders, head of the Sanders Exterminator Corporation of New York, died at Jamaica Hospital on Long Island, New York, after a brief illness, August 17, 1943. He was 59 years old, having been born at Round Hill, Annapolis County, Nova Scotia, Canada, March 28, 1884. Burial was at Round Hill. George Sanders received his elementary education in Nova Scotia and later attended the University of Toronto and the Ontario Agricultural College, where he received the B.S.A. degree in 1907.

Following his college days Sanders' official connections included the following: Nursery Inspector and Assistant to the State Entomologist of Illinois, 1907–10; Assistant Entomologist, in Charge of Insecticide Investigations, Canada Department of Agriculture, 1910–21; In Charge of Research, Dosch Chemical Company, Louisville, 1921–23; General Manager, Deloro Chemical Company, Ontario, 1923–25; New York Insecticide Company, 1925–27; In Charge, Insecticide Research, Ansbacher-Siegle Corporation in New York City, 1927–29, and since 1929 has engaged in commercial pest control work under the name Sanders Exterminator Corporation. He was one of the first technically trained entomologists to enter the field of commercial pest control.

Sanders was a member of many scientific and commercial societies, including: Fellow of the American Association for the Advancement of Science, Charter Member of the Canadian Society of Technical Agriculturalists, New York Pest Control Association, and Society of Industrial and Consulting Entomologists; also Member of the American Association of Economic Entomologists, American Society of Tropical Medicine, American Phytopathological Society, Entomological Society of America, New York Entomological Society, and the National Pest Control Association.

The writer knew George Sanders from the time he entered official duties with the Illinois State Entomologist's Office in 1907. He was a tireless worker and no job was too menial if it promised results of possible value in connection with his studies. He had many friends and to these he was always loyal and generous. His beaming jolly personality endeared him to all who knew him. He was resourceful, as evidenced by his technical research as well as his commercial operations. He was an insecticide chemist of rare ability as well as a scientist with a broad knowledge of his chosen vocation—entomology. During his lifetime he was the author of many papers dealing with insects and insecticides. His research contributions in the fields of fumigation and general exterminating are widely used by the pest control industry today, and his earlier studies with orchard insecticides were stepping-stones to present day practices. Perhaps his largest achievements and contributions to science were in the field of chemical control of insects.

George had several hobbies, but perhaps the two which he enjoyed most were hunting and growing roses. He preferred hunting big game in Canada and enjoyed making carving sets with antler handles for his friends.

George E. Sanders was married in July, 1913, to Georgeina Roop of Annapolis Royal, Nova Scotia, who survives him.—9-27-43.

J. J. DAVIS

John Calhoun Hamlin
1896-1943

John Calhoun Hamlin, employed as Senior Entomologist, Cereal and Forage Insect Investigations, Bureau of Entomology & Plant Quarantine, United States Department of Agriculture, died after a brief illness, at Starkville, Mississippi, June 8, 1943.

Doctor Hamiin was born at Anderson, South Carolina, September 25, 1896, and was graduated by Clemson College with the degree of B.S. in 1916. He received his M.S. in 1918, and a Ph.D. in 1928 at Ohio State University.

Doctor Hamlin served the Federal Horticultural Board as Plant Quarantine Inspector in 1918–19. From 1923 to 1924 he was engaged by the Commonwealth of Australia in the study, collection and introduction of the insect enemies of the prickly pear cactus which had overrun much of the Province of Queensland. Dr. Hamlin was Officer in Charge of this project, in 1923–24, and was successful in introducing species of *Dactylopius* and *Chelinidea* which proved important to the final success of this work.

Entering the Federal Bureau of Entomology in 1924, he was employed in dried fruit insect investigations at Fresno, California, until 1927. On June 13, 1928 he was transferred to assist in the alfalfa weevil investigations at Salt Lake City, Utah. In this project Dr. Hamlin's services were particularly valuable as he reorganized and improved the work in all of its phases. In 1936, he was placed in charge of the project which was terminated in July 1940, after the completion of investigations of the moot question of the liability of weevil transport in alfalfa hay.

At that time Dr. Hamlin prepared a detailed report which contains an able and lucid exposition of the entire alfalfa weevil project over a period of 30 years, and which awaits opportunity for publication.

After a brief assignment to studies of the biology of the mormon cricket, at Winnemucca, Nevada, Dr. Hamlin was sent, in November 1942, to State College, Mississippi, to initiate the entomological phases of a cooperative project for the breeding of corn hybrids for commercial use in the South. He had but organized this work when death intervened.

John Calhoun Hamlin

Dr. Hamlin will be remembered, by his technical associates, for his unusual ability in the fields of insect ecology and biology, and in the exposition of his results.

He is survived by his wife, and by two children from a former marriage.

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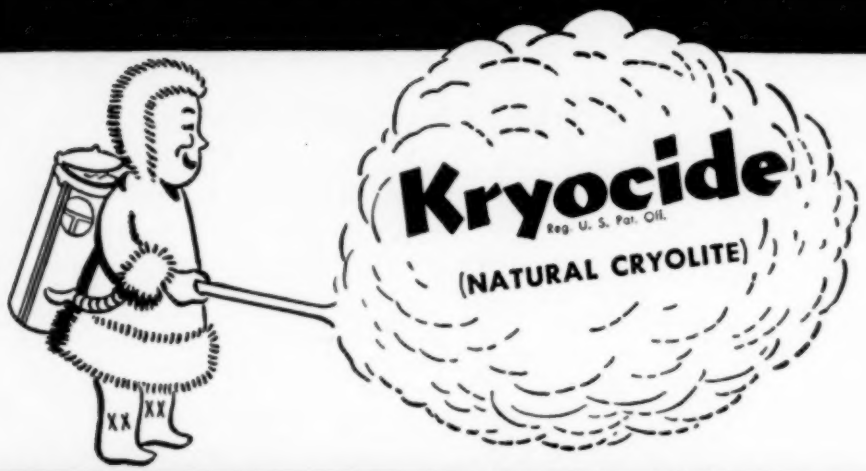

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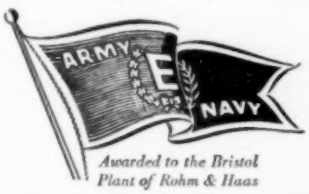

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